Geospatial analysis of the Khorezm oasis in terms of its vegetation cover and the impact of vegetation criteria on the desertification process

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Abstract. Desertification is one of the main environmental problems in arid and semi-arid regions such as the Khorezm oasis. Desertification directly affects soil fertility and the living standards of local residents. In this study, we studied the role of vegetation cover in the desertification process in the Khorezm oasis. We analyzed vegetation characteristics using Sentinel-2 satellite data. Based on these indicators, we developed a Vegetation Quality Index (VQI) to assess vegetation cover, drought tolerance, erosion protection, and drought risk across the study area. The results of our study showed that vegetation degradation is spatially unevenly distributed across the oasis. Approximately 16.07% of the buffer zone and 4.71% of the oasis were identified as areas with very high desertification risk in terms of vegetation cover density. The drought resilience analysis showed that 40.17% of the oasis is moderately vulnerable, indicating the need for targeted measures for effective land management. Areas with relatively high erosion risk accounted for 41% of our study area, while fire risk was limited, with 3.2% of the oasis area identified as high risk.

Keywords: Vegetation cover, Geospatial analysis, Remote sensing, Vegetation Quality Index (VQI), Drought tolerance, Erosion resistance, Fire risk, Soil degradation.

1 Introduction

Desertification is a global environmental problem in arid and semi-arid regions, threatening ecosystems, agriculture and the livelihoods of millions of people. Desertification, defined as land degradation, is the result of natural and anthropogenic factors, with climate change and poor land management being recognized as the main factors. Among the various indicators of desertification, vegetation cover is the most important in maintaining ecosystem stability and soil quality. Therefore, understanding the dynamics of vegetation and its interaction with environmental factors is essential for developing effective desertification control strategies.

The Khorezm oasis, located in arid regions, is a favorable region for understanding the interaction between vegetation cover and desertification processes. The Khorezm oasis, like most regions in Central Asia, faces serious environmental challenges such as soil degradation, water scarcity, and the impact of human activities such as agriculture and urbanization [1]. The vegetation cover in this region not only protects against desertification, but also supports local biodiversity and agriculture. However, vegetation degradation exacerbates desertification, leading to soil degradation and reduced ecological stability.

Today, modern advances in remote sensing technology allow for continuous monitoring of various indicators of plant cover. In particular, there are opportunities for remote study of the state of plants through indices such as the normalized difference vegetation index (NDVI), soil-adapted vegetation index (SAVI), expanded vegetation index (EVI), and leaf area index (LAI). These indices allow studying the characteristics of various plants, including their impact on desertification [14,15].

The purpose of our research is to determine the plant cover of the Khorezm oasis and its sensitivity to desertification. For this purpose, we have developed a plant quality index (VQI) for the Khorezm oasis, summarizing such indicators as plant resistance to drought, drought resistance, erosion resistance, and plant density.

2 Materials and methods

2.1 Study area

The Khorezm oasis, located in the arid zone of Central Asia, is the study area for this research. The oasis is in the lower reaches of the Amudarya River and has an area of approximately 28,866.7 square kilometers, encompassing the oasis and a surrounding buffer zone. The region experiences a harsh continental climate with hot, arid summers and cold winters and is highly susceptible to desertification processes. The average annual precipitation is low, and the region relies heavily on irrigation from the Amudarya river for agricultural needs.

The Khorezm oasis is historically significant, having been a center of agriculture and human settlement for centuries. It is home to diverse arrays of ecosystems, including irrigated agricultural lands, natural vegetation, and deserts. The oasis supports various plant species, from perennial trees and shrubs to seasonal grasses, which play significant roles in soil stabilization, water cycling, and regional biodiversity. However, the region has severe environmental challenges such as soil degradation, water shortage, and the impacts of human activities such as large-scale agriculture, deforestation, and urbanization.

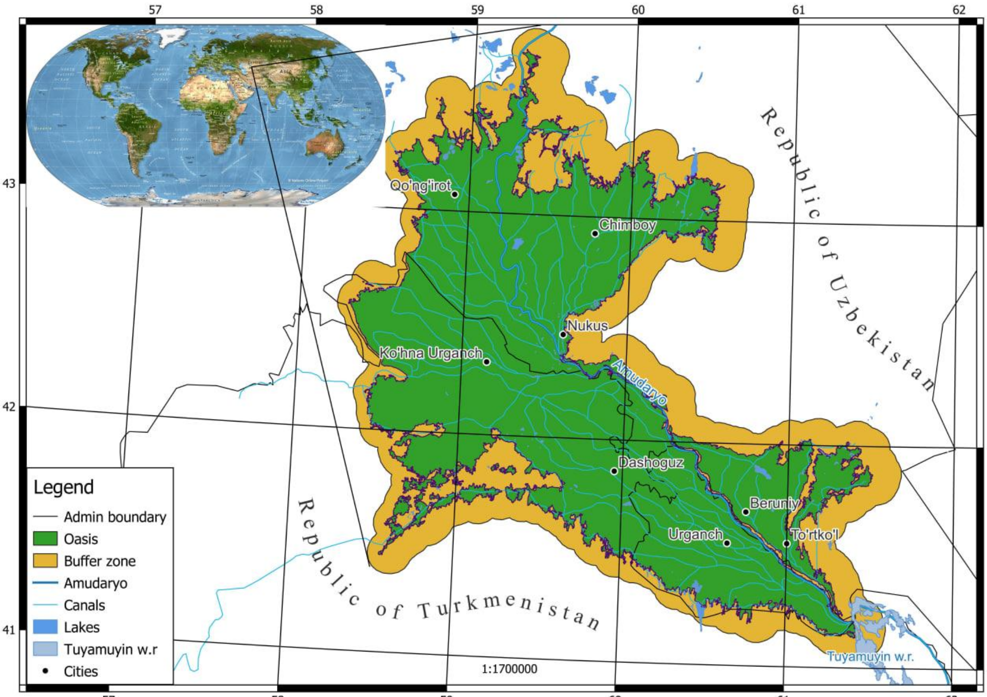

Figure 1. Location of the Khorezm oasis.

The buffer zone of the oasis, which covers an area of approximately 46,578.17 square kilometers, is made up of a mosaic of desert scenery, sparse vegetation, and transitional ecosystems. The buffer zone is a critical interface between the oasis and the surrounding desert environment and influences the ecological processes of the region. The buffer zone is very vulnerable to desertification due to its arid character and sparse vegetation cover and therefore is a key zone to monitor and preserve. (Figure 1)

The Khorezm oasis and buffer zone offer the unique opportunity to explore the interlinkages between vegetation cover and desertification processes. The contrasting ecosystems of the area, along with its susceptibility to environmental stressors, make it an ideal example for researching the role played by vegetation in buffering desertification. By evaluating the cover of vegetation, drought tolerance, erosion resistance, and fire danger in the area, the study aims to provide beneficial information pertaining to the ecological health of the oasis and the broader implications on sustainable land management in dry lands.

2.2 Methodology

This method was developed within the MEDALUS project to assess the vegetation quality index in relation to desertification, and we adapted it for the oasis, taking into account the natural geographical features of the Khorezm oasis. The main goal of this methodology is to develop a vegetation quality index (VQI). It includes indicators such as fire risk, erosion, drought resistance and plant cover density. The VQI is calculated using a formula synthesized for these parameters (Formula 1). The vegetation quality index of the Khorezm oasis was divided into 5 classes in terms of desertification susceptibility: Very dangerous, dangerous, moderately dangerous, safe and very safe. This approach allows us to cartographically depict which parts of the oasis territory are most susceptible to desertification. (Figure 2)

2.2.1 Data Collection

To conduct this research, we used multi-sensor satellite imagery, including Sentinel-2 imagery (10m), Landsat 8 OLI/TIRS imagery (30m).

Main spectral bands (visible, NIR, red edge) were acquired for the main growing seasons with <10% cloud cover. All images went through the following processing steps:
- Radiometric and atmospheric correction
- Geometric registration to WGS84/UTM zone 41N
- Resolution standardization (10m for Sentinel-2, 30m for Landsat 8)

Additional data included:
- 120 ground reference points
- Local climate records

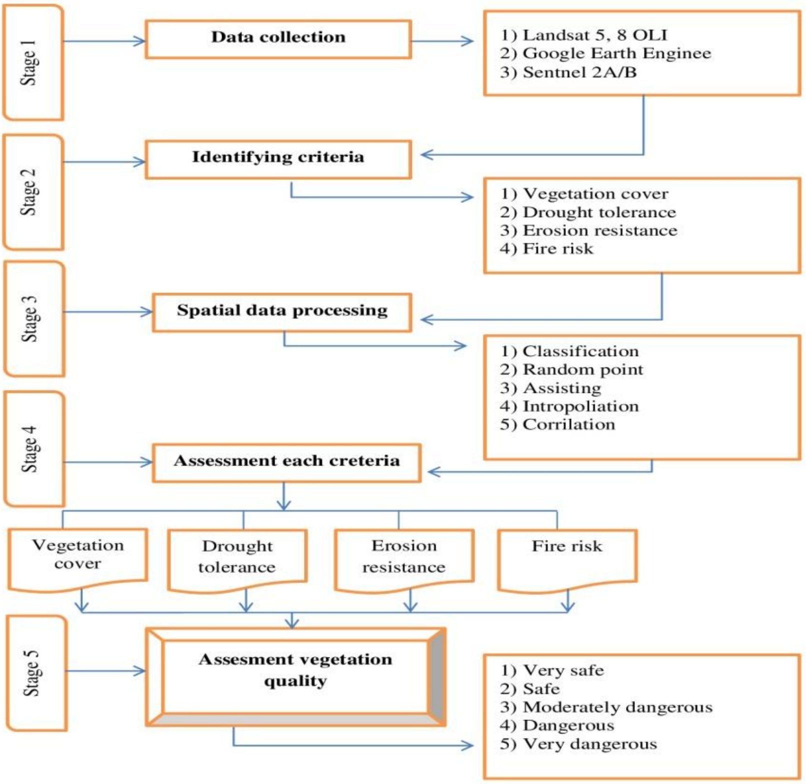

Figure 2. Flowchart of the methodology.

Vegetation cover provides important information about the ecosystem of a region. A high density of vegetation cover indicates a healthy ecosystem, while a sparse vegetation cover indicates a weak ecosystem in the region. The weakness of vegetation cover can increase soil erosion in the region and also disrupt the stability of the microclimate, resulting in favorable conditions for desertification in the region.

2.3 Analysis

With the rapid increase in the availability of remote sensing data, a number of researchers have also increased their ability to use vegetation indices to assess desertification processes, including the normalized difference vegetation index (NDVI) [2], the soil-adapted vegetation index (SAVI) [3], the enhanced vegetation index (EVI) [4], and the leaf area index [5]. Although these indices are widely used in desertification assessment, no single vegetation index can adequately describe desertification for all terrestrial ecosystems [6]. Therefore, we used the following formula, which is widely used by world scientists to assess the impact of the vegetation quality index on the desertification process. (Formula 1)

$$VQI = (Fr \times Ep \times Dr \times PC)^{1/4} \quad (1)$$

Here, Fr is fire risk, Ep is erosion protection, Dr is drought tolerance, and Pc is vegetation cover. [7]

To calculate the quality index of the vignette, we used images from the Sentinel-2 satellite and applied the supervised classification technology with the maximum likelihood algorithm [8, 9]. The pixel resolution of the raster layers was changed from 10 m to 30 m to ensure that the classified map had the same spatial dimensions.

3 Results

The Vegetation Quality Index (VSI) was calculated by combining four main indicators (Formula 1). The density of vegetation cover was calculated from the NDVI (Normalized Difference Vegetation Index) and reclassified. The NDVI values were divided into five main classes (less than 0.15; 0.15 to 0.25; 0.25 to 0.35; 0.35 to 0.45 and more than 0.45) (Figure 3). Approximately 120 sample points were used to check the accuracy of the data.

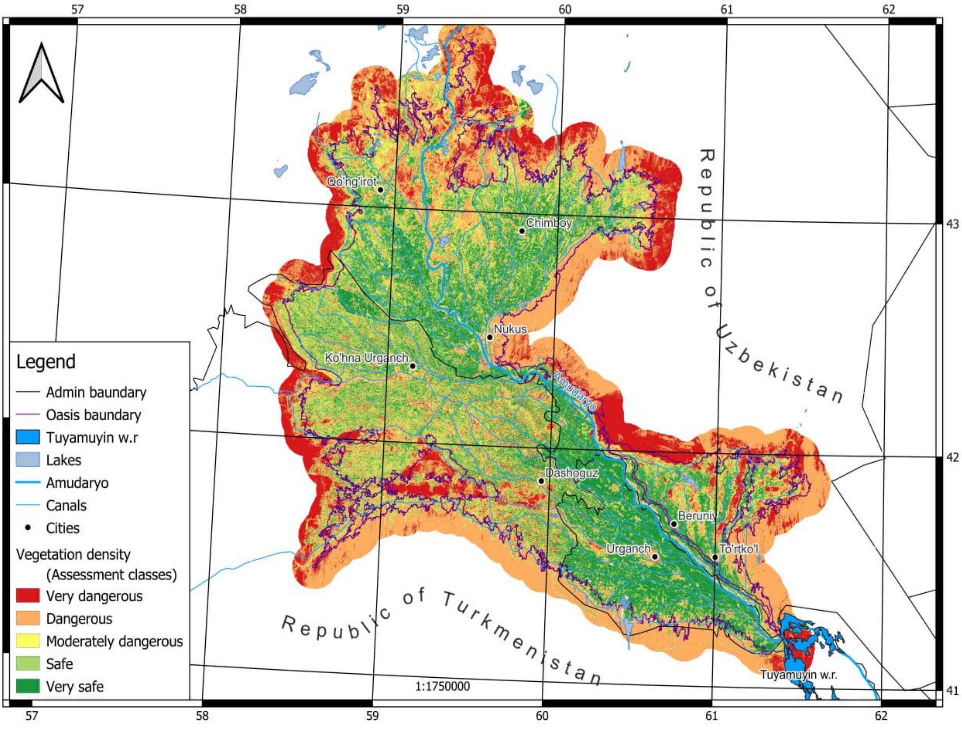

Figure 3. Vegetation density map of the Khorezm oasis

The density of vegetation cover in the Khorezm oasis provides important information about the state of the vegetation cover of this area. It is divided into different assessment classes, reflecting the complex interaction between environmental factors and biodiversity.

Table 1. Vegetation density of the Khorezm oasis

T/r	Assessment classes	With buffer zone (in km/sq.)	Area (in%)	Oasis area (in sq km)	Area (in%)
1	Very dangerous	7486,973	16,074	1359,887	4,710919
2	Dangerous	16033,03	34,42176	5719,216	19,81251
3	Moderately dangerous	6672,322	14,325	5825,916	20,18213
4	Safe	10631,42	22,82491	10264,99	35,55997
5	Very safe	5754,426	12,35434	5696,686	19,73445
6	**General**	**46578,17**	**100**	**28866,7**	**100**

The oasis is divided into five assessment classes, including: very dangerous, dangerous, moderately dangerous, safe and very safe. Each class indicates the level of ecological risk affecting the vegetation cover, which is crucial for the preservation of local ecosystems.

The analysis showed that a certain part of both the buffer zone and the oasis is classified as very dangerous and hazardous. For example, the “Very Dangerous” category covers 16.07 percent of the buffer zone and 4.71 percent of the oasis area. (Table 1)

Also, part of the oasis is classified as safe (35.56%) and very safe (19.73%). This indicates areas where environmental conditions are stable and conducive to healthy plant growth. However, the small percentage of very safe areas indicates that improvements are needed to increase biodiversity and ecological sustainability throughout the oasis.

The next criterion for determining the plant quality index is the degree of drought tolerance. Drought tolerance or tolerance is a broader term used to describe the ability of plants to survive, avoid, or tolerate drought conditions [10]. In general, drought tolerance refers to the ability of plants to survive under water scarcity.

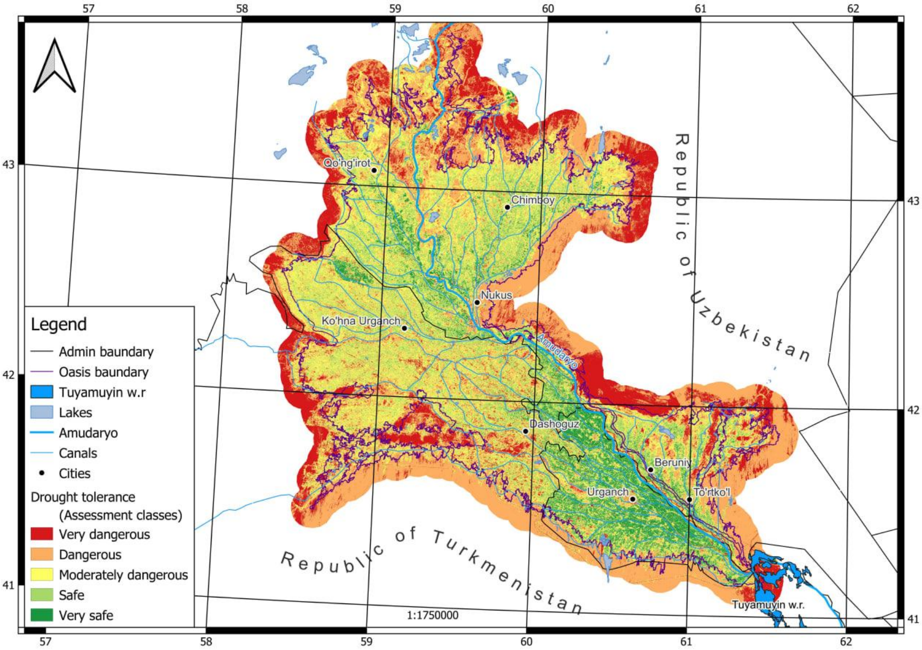

Figure 4. Drought tolerance map of the Khorezm oasis.

The drought tolerance of plants depends on several adaptive mechanisms. These adaptations are determined by evolutionary, ecological, and genetic elements. They are important for stabilizing ecosystems and desertification in arid regions.

Table 2. Drought tolerance table of the Khorezm oasis

Assessment classes	**With buffer zone (in km/sq.)**	**Area (in%)**	**Oasis area (in sq km)**	**Area (in%)**
Very dangerous	7486,973069	16,07399481	1359,887	4,710919
Dangerous	16033,0274	34,42176121	5719,216	19,81251
Moderately dangerous	12711,19988	27,29003551	11594,41	40,16534
Safe	7443,419241	15,98048786	7312,6	25,3323
Very safe	2903,553157	6,233720615	2880,582	9,97891
General	**46578,17275**	**100**	**28866,7**	**100**

According to recent assessments of its vulnerability in different zones, the Khorezm oasis has a high drought tolerance. The oasis's vulnerability classes range from "very dangerous" to "very safe," totaling six. (Figure 4)

The “high risk” category covers about 16.07 percent of the buffer zone, while only 4.71 percent of the oasis area is at risk. In comparison, the share of “high risk” areas is about 34.42 percent of the buffer zone and 19.81 percent of the oasis, indicating that a much larger portion is facing a relatively high drought threat. (Table 2)

Most importantly, almost 40.17% of the oasis was classified as “moderately vulnerable”, which, although it indicates moderate but serious vulnerability, actually puts almost half of the oasis area at risk. On the other hand, the buffer zone described as “safe” only covers 15.98%, and the extended area of the oasis itself, which is 25.33%, was found to be equally resilient. These "safe" zones are crucial for ecological balance and can serve as a refuge during periods of extreme drought.

Overall, this analysis shows that the Khorezm oasis is at very high risk of drought. Therefore, strategies should be aimed at increasing drought resilience. Oasis management is necessary to ensure agricultural and environmental sustainability, and to ensure that the region is resilient to adverse climatic conditions.

The resistance of plants to erosion is the third main factor in its determination. Perennial trees and shrubs have a high resistance to erosion, while seasonal grasses and plants have a low resistance to erosion. In the Khorezm oasis, groves, perennial trees, and shrubs have a very high resistance to erosion, while ephemeral plants, mainly in the buffer zone and inland deserts, were classified as very dangerous areas. (Figure 5)

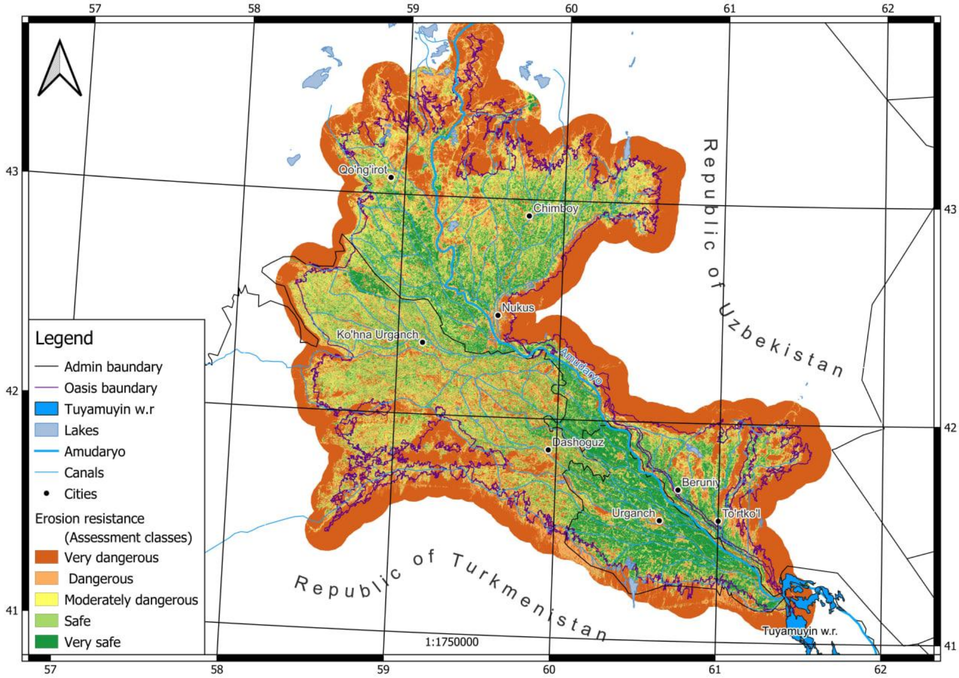

Figure 5. Erosion resistance map of the Khorezm oasis

The erosion resistance of vegetation in the Khorezm oasis has been divided into separate assessment classes and is being assessed based on the level of erosion risk in their areas. Such an assessment is very important for understanding the impact of desertification processes, as well as for land management and sustainable use in the designated area.

The "Very Dangerous" assessment area in the oasis covers an area of approximately 19,094 km², accounting for 41% of the total surveyed area and 14.5% of the oasis area. In contrast, the "Safe" and "Very Dangerous" categories cover more stable areas, with 5,450 km² (11.7%) and 7,808 km² (16.8%), respectively. (Table 3)

Table 3. Table for assessing the level of erosion resistance of plants in the Khorezm oasis

T/r	Assessment classes	With buffer zone (in km/sq.)	Area (in%)	Oasis area (in sq km)	Area (in%)
1	Very dangerous	19093,57493	40,99253992	4207,424	14,57536
2	Dangerous	7852,977623	16,85978136	5745,526	19,90365
3	Moderately dangerous	6373,78216	13,68405448	5910,5	20,47515
4	Safe	5449,555924	11,69980685	5288,434	18,32019
5	Very safe	7808,282115	16,7638233	7714,812	26,72564
6	**General**	**46578,17275**	**100**	**28866,7**	**100**

Assessing the erosion resistance of vegetation in the Khorezm oasis requires a multidisciplinary assessment that includes ecological, agrotechnical, and geomorphological data. The Khorezm oasis has an arid climate, irrigated agriculture, and soils prone to water and wind erosion. A systematic assessment of the erosion resistance of vegetation in the region is important in studying desertification.

The Khorezm oasis is characterized by a unique fire hazard due to its arid climate, agriculture, and human activity. For example, the fire that occurred in the Lower Amudarya State Biosphere Reserve on November 27-30, 2021. The fire occurred in the 11th ring-timber forest in the Nazarkhan section of the biosphere reserve, which has a total area of 68,717.8 hectares. As a result, the area damaged by the fire in the biosphere reserve amounted to 174.24 hectares.

Important insights into fire risk were identified through vegetation indices and drought determinations derived from remote sensing data. (Figure 6)

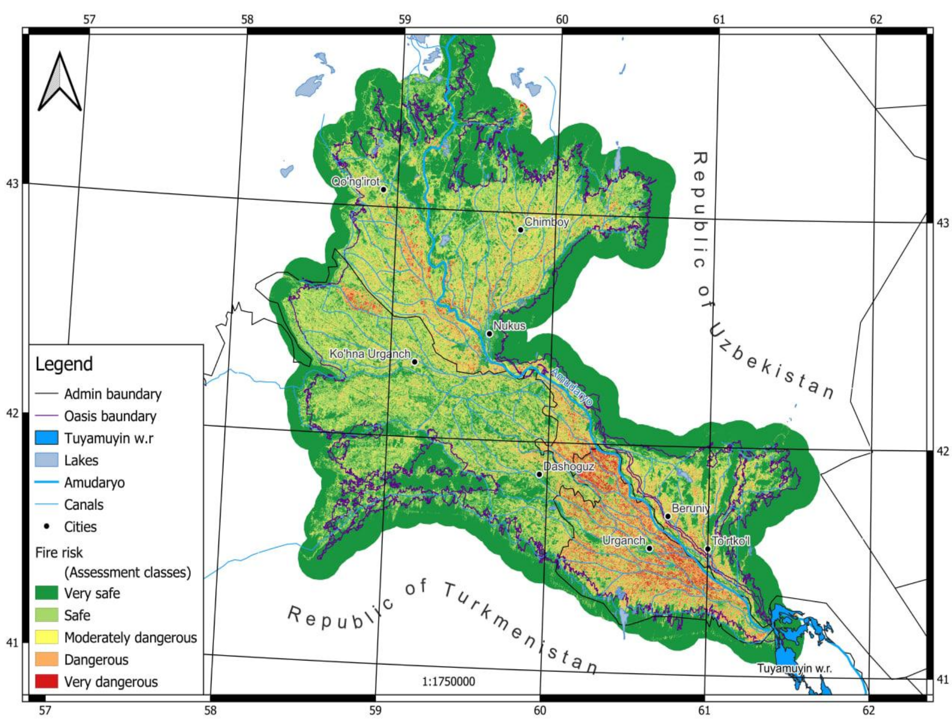

Figure 6. Vegetation-based fire risk map of the Khorezm oasis

Fires destroy vegetation, which stabilizes the soil with its roots and reduces albedo. Without vegetation, the risk of soil erosion by wind and water also increases. For example, repeated fires in the Mediterranean basin have led to soil degradation, which has exacerbated desert-like conditions.

The risk of plant-based fires in the Khorezm oasis can be said to be practically very low. (Table 4)

Table 4. Vegetation-based fire hazard table of the Khorezm oasis

T/r	Assessment classes	With buffer zone (in km/sq.)	Area (in%)	Oasis area (in sq km)	Area (in%)
1	Very safe	23520,00047	50,495759	7079,103	24,52342
2	Safe	12711,19988	27,29003712	11594,41	40,16534
3	Moderately dangerous	4592,546841	9,859869636	4496,497	15,57676
4	Dangerous	4825,009334	10,35894998	4772,517	16,53295
5	Very dangerous	929,4162236	1,995390166	924,1689	3,201505
6	**General**	**46578,17275**	**100**	**28866,7**	**100**

More than 50% of the buffer zone (23,520 km²) was classified as "Very Safe", with vegetation in these areas being mostly sparse and posing little risk of fire.

We can see that a large part of the oasis area, i.e. 40% (11,594 km²), is in the "Very Safe" assessment category. However, 3.2% of the oasis area (924 km²) is in the "Very Dangerous" assessment category. Table 4

The vegetation quality index card of the Khorezm oasis was developed based on the above data (formula 1). (Figure 7)

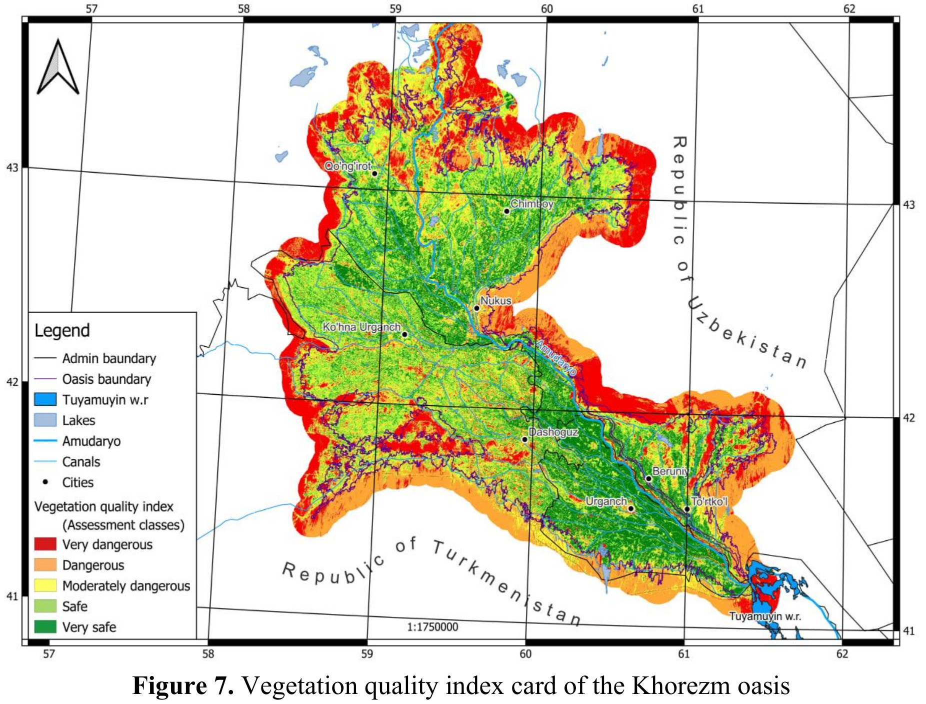

Figure 7. Vegetation quality index card of the Khorezm oasis

Vegetation cover is one of the important indicators for assessing desertification in arid and semi-arid regions. Vegetation cover prevents sand migration in sandy deserts and reduces the intensity of soil erosion, creating conditions for local residents and their livestock [7]. Therefore, plants enrich the organic soil and have the ability to reduce the intensity of soil erosion, thus improving its cohesion and quality.

Table 5. Vegetation quality index of the Khorezm oasis

Assessment classes	With buffer zone (in km/sq.)	Area (in%)	Oasis area (in sq km)	Area (in%)
Very dangerous	8437,514	18,07406122	1860,194	6,461414
Dangerous	15217,07	32,59659833	6310,324	21,91901
Moderately dangerous	7134,312	15,28246257	6231,442	21,64502
Safe	9639,38	20,64858728	8266,17	28,71268
Very safe	6255,452	13,39985005	6121,14	21,26188
General	**46683,728**	**100**	**28789,27**	**100**

It is worth noting that the buffer zone is dominated by high risk categories. More than 50% of its area falls into the "Hazardous" (32.60%) and "Very Hazardous" (18.07%) zones, indicating a serious environmental problem that causes soil degradation. In contrast, the oasis area shows greater resilience, with almost 50% classified as "Safe" (28.71%) and "Very Safe" (21.26%). (Table 5)

In general, the vegetation quality index is an important indicator in describing oasis vegetation cover and is one of the decisive factors in analyzing the desertification process.

4 Discussion

Desertification threatens arid lands like the Khorezm oasis, where vegetation plays a pivotal role in ensuring ecological stability. Geospatial analysis and remote sensing were used in this research to assess the health of vegetation and its impact on desertification. Key findings confirm that 16% of the buffer zone and 5% of the oasis are "very dangerous" as they have negligible vegetation and 40% of the oasis is comparatively vulnerable to drought. High erosion risk prevails over 41% of the region, with still limited fire risks (3% risk high).

VQI outlined areas of degradation in addition to affirming sustainable land management requirements. Desertification control by the study has recommended forest cover re-vegetation through drought-resistant plantations and erosional control mechanisms. Conservation of vegetation is paramount to soil stability, water retention, and sustainability in the long term in Khorezm and arid ecosystems in general.

This study analyzed several studies conducted in arid regions that are similar to the natural geographical features of the Khorezm oasis; for example, Egypt [11], Iran [12] and Morocco [8]. In this study, we modified the original values of the proposed approach of the researchers mentioned above and adapted it for the Khorezm oasis.

The study has great theoretical and practical significance. By measuring the protective effect of vegetation against desertification in the Khorezm oasis, the study empirically substantiates broader ecological theories of ecosystem resilience in arid conditions. The findings are consistent with and build on previous studies in similar settings, such as those conducted in the Draa Valley of Morocco [13] and the Nile Delta of Egypt [11], and provide region-specific information for the fragile ecosystems of Central Asia.

The development of the Vegetation Quality Index (VQI) represents an advancement in desertification monitoring techniques. It is derived from established vegetation indices such as NDVI [2] and SAVI [3], but is enhanced by combining multiple risk factors into a single overall measure.

In practical terms, this study addresses the pressing sustainability issues raised in UNCCD reports. The clear evidence on erosion risk (41% of the study area) and drought (40% of the oasis) provides concrete information that policymakers can use to develop land management strategies. These results are further validated by similar findings from Iran [12], which suggest regional trends that require collaboration.

The focus on research on the microclimate regulation and soil stabilization functions of plants serves to anchor key ecological principles in empirical, locally relevant evidence. This gap is modeled by a theoretical model, such as Levitt (1980) [10], on the response of plants to stress and their retention at ground level. The fact that desertification threatens about 40% of the world's land area, according to UN estimates a few years ago, makes this research, which is locally relevant in nature but has global applicability, even more important for developing adaptive response mechanisms in the world's deserts.

5 Conclusion

In this study, we developed a comprehensive vegetation quality index (VQI) for the Khorezm oasis, taking into account factors such as vegetation indicators, erosion resistance, drought resistance, and fire risk using remote sensing.

According to the results of our study, a large area of the Khorezm oasis is at risk of desertification, with 16.07% of the buffer zone and 4.71% of the oasis being very vulnerable to vegetation density. When we studied the level of vegetation resistance to drought, it was found that 40.17% of the oasis area was moderately vulnerable. Also, when we analyzed erosion resistance, it was found that almost 41% of the Khorezm oasis was at high risk of erosion.

The results of this study showed that the fragile ecosystem of the Khorezm oasis needs protection, which indicates the need to develop a scientifically based system of measures to prevent desertification.

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