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Research Article

Remote Sensing–Based Online Monitoring Systems for Assessing Degradation of Rainfed Lands

*O'zbekhon Muxtorov [1], D. Shog'darov [2]

[1] Tashkent Institute of Irrigation and Agricultural Mechanization Engineers National Research University (TIIAME NRU), Tashkent, Uzbekistan.
[2] Karshi State Technical University, Karshi, Uzbekistan.

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***Corresponding author:** **O'zbekhon Muxtorov**
Tashkent Institute of Irrigation and Agricultural Mechanization Engineers National Research University (TIIAME NRU), Tashkent, Uzbekistan.

Abstract
In recent years, the quality of land resources has significantly deteriorated due to climate change and anthropogenic pressures. Rainfed lands, which rely solely on precipitation without artificial irrigation, are particularly vulnerable to climate change. In these areas, degradation processes such as soil erosion, reduction of organic matter, and weakening of vegetation occur rapidly. Regular and large-scale monitoring of these changes through traditional methods is challenging, while modern remote sensing technologies, especially the Google Earth Engine (GEE) platform, offer significant opportunities in this regard. This article discusses the approach of monitoring the degradation of rainfed lands using the Normalized Difference Vegetation Index (NDVI) based on GEE.

Keywords: *GEE (Google Earth Engine), NDVI (Normalized Difference Vegetation Index), Landsat 8/9, GIS, spectral index, Java, biomass, Sentinel-1.*

Introduction

The sustainable management of land resources has become a critical global concern in the context of climate change, water scarcity, and environmental degradation. In arid and semi-arid regions such as Uzbekistan, where a significant portion of agricultural land is rainfed (lalmi), land degradation has emerged as one of the most pressing ecological and socio-economic challenges. The degradation of rainfed lands leads to declining soil fertility, loss of vegetation cover, and reduced agricultural productivity, ultimately affecting rural livelihoods and national food security.

In recent years, the integration of remote sensing (RS) and Geographic Information Systems (GIS) technologies has transformed traditional methods of environmental observation and monitoring. These technologies make it possible to observe large-scale spatial and temporal changes in vegetation and soil conditions using high-resolution satellite imagery. Among them, the Google Earth Engine (GEE) platform provides an advanced cloud-based computational environment that allows real-time processing and analysis of vast geospatial datasets.

Monitoring vegetation cover and land degradation dynamics through spectral indices such as the Normalized Difference Vegetation Index (NDVI) has proven to be one of the most effective approaches for identifying degraded areas and tracking ecological changes over time. NDVI-based analysis offers quantitative insights into vegetation health, density, and productivity, enabling decision-makers to assess the sustainability of land-use practices.

Given the increasing pressure on natural resources in Uzbekistan, there is a strong need to develop automated, web-based systems for monitoring rainfed land degradation. Such systems can support data-driven decision-making, facilitate early warning mechanisms, and contribute to the sustainable development of agriculture. This study focuses on the design and implementation of an online monitoring system for assessing vegetation cover and degradation processes in rainfed areas using Google Earth Engine technology.

Literature Review

Over the last two decades, remote sensing has become one of the most powerful tools for monitoring and analyzing environmental change. According to Hansen et al. (2013) and Zhu and Woodcock (2014), satellite data such as Landsat, Sentinel, and MODIS provide reliable time-series information that enables accurate detection of land-cover changes. These datasets, when processed through GIS and cloud-based platforms, facilitate the assessment of vegetation dynamics, soil moisture, and erosion patterns at multiple spatial and temporal scales.

Researchers such as Wessels et al. (2012) emphasize that NDVI-based monitoring enables precise evaluation of vegetation condition and long-term degradation trends, particularly in arid ecosystems. The combination of spectral indices (NDVI, SAVI, EVI) with climate and soil parameters allows a more comprehensive assessment of degradation drivers and restoration potential.

The Google Earth Engine (GEE) has revolutionized geospatial data analysis by providing access to a vast repository of satellite imagery and powerful cloud computing capabilities. Studies by Gorelick et al. (2017) and Azzari & Lobell (2017) demonstrate that GEE enables researchers to conduct large-scale environmental analyses without the need for high-end local computing resources. Its real-time data processing and interactive visualization tools make it particularly suitable for agricultural monitoring, deforestation assessment, and climate change impact analysis.

In the Central Asian context, Durmanov & Kholikulov (2024) and Yusupov (2023) have shown that using GEE for monitoring arid lands in Uzbekistan significantly improves the accuracy and timeliness of ecological assessments. They highlight that GEE-based NDVI analyses help identify areas affected by vegetation decline and inform the development of targeted restoration strategies.

Rainfed agriculture in Uzbekistan depends primarily on natural precipitation, making it highly vulnerable to climatic variability. According to FAO (2023) and UNDP Uzbekistan (2024), more than 40% of agricultural land in the country is categorized as rainfed, and a substantial part of it faces moderate to severe degradation. The main contributing factors include overgrazing, poor land management, deforestation, and inefficient agricultural practices.

Previous research (Karimov & Turaev, 2022; Ismailov, 2023) indicates that the lack of systematic monitoring tools and limited use of geospatial technologies hinder effective land management in these areas. Integrating NDVI-based monitoring through GEE provides an innovative solution for identifying degradation trends and supporting evidence-based policy-making.

Although several studies have analyzed land degradation using remote sensing techniques, few have developed automated online monitoring systems specifically designed for rainfed land assessment in Uzbekistan. Existing models often rely on static data and lack integration with cloud-based geospatial platforms.

This study addresses that gap by developing a web-based monitoring model using GEE that automates data collection, NDVI computation, and visualization of degradation trends. The research contributes to improving environmental monitoring infrastructure and enhancing the sustainability of land management in arid regions of Uzbekistan.

Methods and Results

Monitoring the condition of land areas is of significant ecological and economic importance and is widely applied in sectors such as agriculture, environmental protection, and urban planning. With the growing demand for efficiency and accuracy, there is an increasing need to develop real-time monitoring systems based on satellite imagery and GIS technologies. In this study, the methodology for developing an online monitoring system plays a crucial role. Today, as in other sectors, the use of web-based electronic maps for monitoring the condition of rainfed lands is becoming increasingly relevant, along with the demand for automated systems that can continuously track land dynamics. Automation of these processes through the creation of specially designed and algorithmically structured web platforms has become one of the key priorities of modern agriculture. Automating the monitoring of rainfed land areas is considered highly beneficial, as traditional monitoring methods currently require significant time, manual labor, and financial costs. As the object of research, this study focuses on the districts of Ko‘kdala, Dehqonobod, Qamashi, G‘uzor, and Chiroqchi in the Kashkadarya region, which contain the largest areas of rainfed land in Uzbekistan. The main goal is to develop an automated system for monitoring crop conditions in these rainfed territories, enhancing the efficiency and sustainability of land management practices.

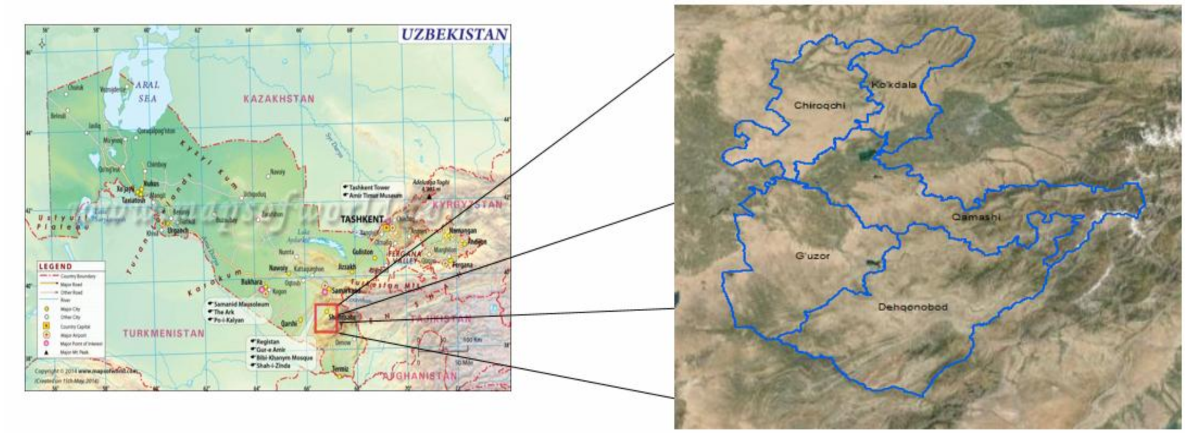

Figure 1: The Study Area — Rainfed Land Regions of Kashkadarya Province (Koʻkdala, Dehqonobod, Qamashi, Gʻuzor, and Chiroqchi Districts)

In this research, an automated system for monitoring crops in rainfed lands of the Kashkadarya region was developed. This automated monitoring system was implemented on the open web-based "Google Earth Engine" platform, which is one of the most advanced and accessible web programming environments for geospatial analysis.

During the system development process, various web programming and styling platforms were utilized to design and implement the interface of the monitoring system.

Within the developed open web-based system, Landsat 8/9 satellite imagery was employed as the primary geospatial data source. Additionally, the Google Earth Engine platform was used for creating the website's visualization interface and overall design layout.

The proposed model, created using cloud-based GIS technologies integrated within the Google Earth Engine environment, consists of the following main components:

1. Data acquisition and preprocessing (satellite image retrieval and filtering);
2. Automated analysis and classification of rainfed land conditions;
3. Visualization and mapping of results through an interactive web interface;
4. User interaction and data export functions for monitoring and reporting purposes.

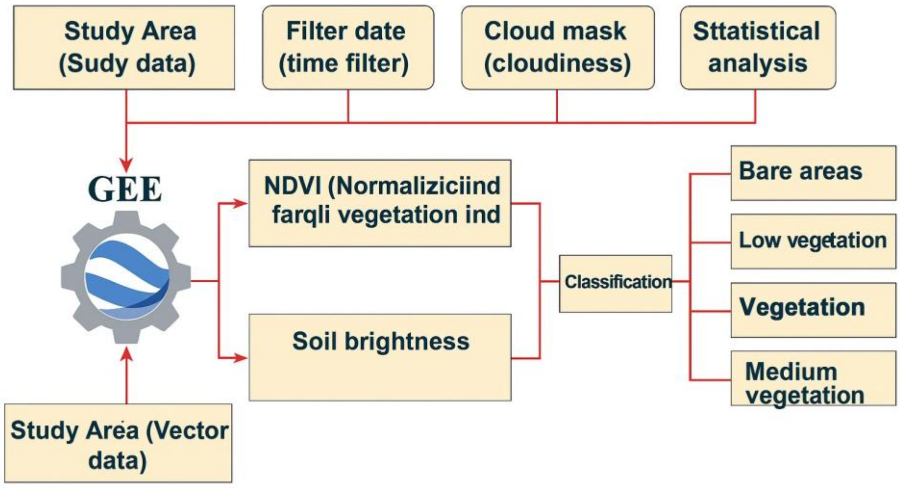

Figure 2: Methodology for Monitoring Vegetation Cover of Rainfed Lands Using the Google Earth Engine Program

The Google Earth Engine (GEE) technology is a cloud-based geographic information system that enables the processing and analysis of large volumes of satellite imagery. This platform allows efficient monitoring of agricultural fields, land resources, and ecological systems.

The main advantages of GEE include: The ability to rapidly process large-scale satellite imagery; Open-source coding environment for data analysis; The possibility to assess vegetation conditions using various spectral indices.

Monitoring Methods for Vegetation Cover of Rainfed Lands. There are several methods for observing changes in vegetation cover in rainfed areas. With the help of the Google Earth Engine, these processes can be performed efficiently and in near real time. Analysis using Landsat imagery: The GEE platform provides access to Landsat (NASA) satellite data, which makes it possible to conduct long-term monitoring of rainfed lands and determine vegetation dynamics over time. Rainfed agriculture represents a specific cropping system that relies mainly on natural precipitation. In such regions, maintaining soil fertility and monitoring vegetation cover are of critical importance. Modern geoinformation technologies — particularly the GEE platform — provide effective tools for analyzing and evaluating the vegetation status of rainfed lands. Within this research, a model for vegetation cover monitoring of rainfed areas was developed using GEE technology, and the algorithm was implemented in the Java programming language within the Earth Engine environment.

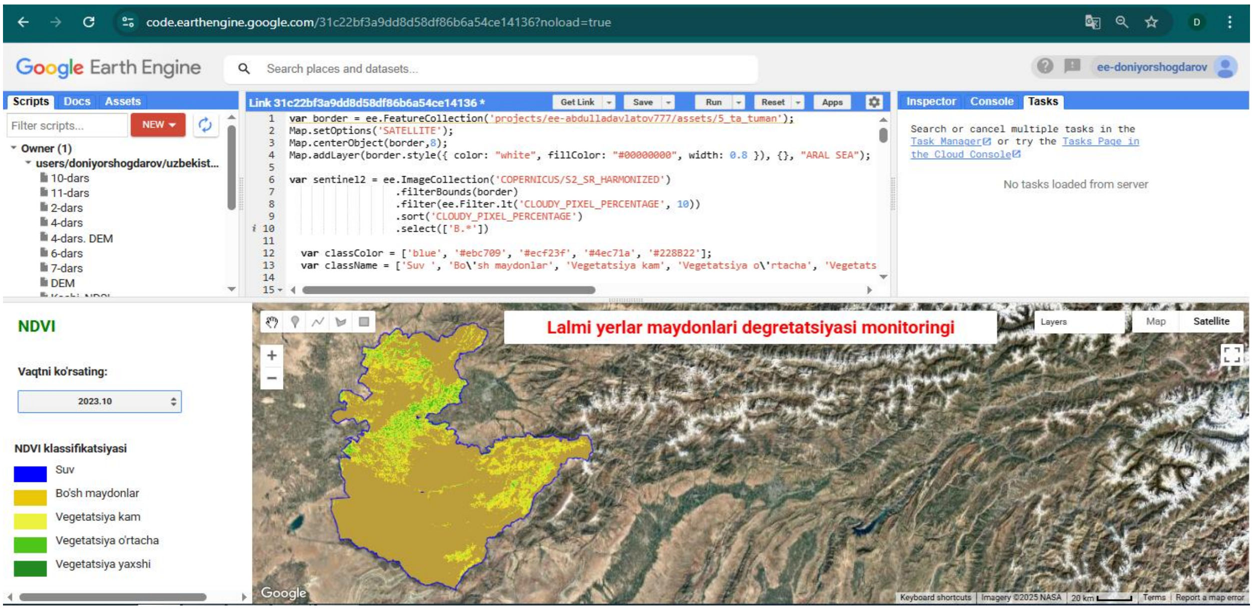

Figure 3. Process of Calculating the Vegetation Index Using the Google Earth Engine Program

In monitoring the vegetation cover of rainfed lands using the Google Earth Engine (GEE) platform, various land characteristics are evaluated, and degradation processes are automatically detected through integrated analytical tools.
The main characteristics assessed include the following:

1. Soil Moisture Assessment – In rainfed areas, soil moisture is one of the main factors influencing vegetation growth. Using GEE, soil moisture can be analyzed based on MODIS and Sentinel-1 radar imagery, allowing for continuous spatiotemporal monitoring of soil conditions.
2. Estimation of Vegetation Biomass and Productivity – To evaluate the biomass and productivity of vegetation in rainfed zones, different satellite datasets and vegetation indices can be employed. Precipitation data from the NASA POWER web platform make it possible to estimate rainfall levels and predict potential crop yields with improved accuracy.

By employing the GEE platform, soil moisture and productivity analysis can be integrated to perform a comprehensive evaluation of vegetation growth conditions in arid and semi-arid regions. The Normalized Difference Vegetation Index (NDVI) is particularly valuable in this regard, as it provides a reliable measure of vegetation health and enables long-term monitoring of land degradation through correlation analysis of temporal changes.

Furthermore, the results obtained through GEE-based monitoring serve as an essential tool for agricultural planning, helping to optimize crop rotation schedules, assess land suitability, and support sustainable resource management in rainfed farming systems.

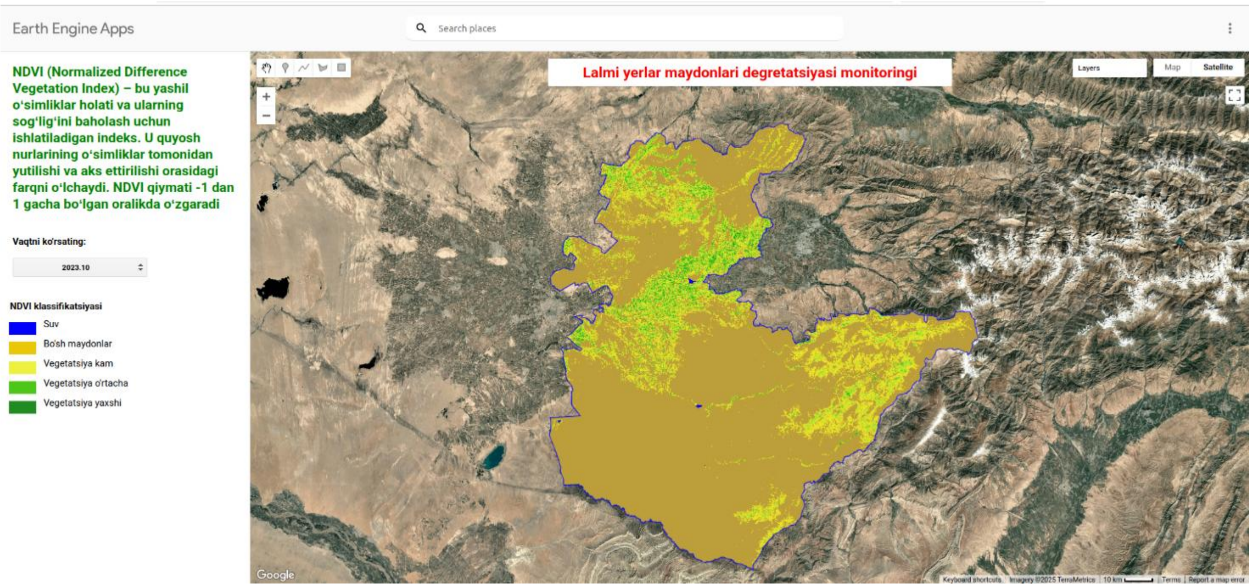

Figure 4. Monitoring of Vegetation Cover in Rainfed Lands During the Autumn Season Using the Google Earth Engine Program

Efficient use of natural resources and the sustainable development of agriculture require continuous monitoring of vegetation cover in rainfed land areas. Modern technologies — particularly cloud computing platforms such as Google Earth Engine (GEE) — serve as effective tools for implementing this process. Through GEE, it is possible to assess and analyze long-term vegetation dynamics of the Earth’s surface, providing valuable insights into biomass growth, crop productivity, and ecological management.

This monitoring framework plays a crucial role in tracking vegetation biomass, managing environmental processes, and enhancing agricultural productivity in rainfed territories. Based on the obtained results, rainfed land areas can be classified into the following four categories:

1. Bare Areas: These are regions with little or no vegetation cover. Due to minimal plant growth, such areas are highly prone to soil erosion and degradation. Bare lands are considered ecologically vulnerable zones that require targeted agro-technical measures for restoration and rehabilitation.
2. Low-Vegetation Areas: These lands possess some vegetation cover but are underdeveloped due to limited moisture availability, low soil fertility, or anthropogenic pressures. Based on monitoring results, such areas can be improved through the introduction of water-saving irrigation technologies and enhanced fertilization systems.
3. Moderate-Vegetation Areas: This category includes lands with stable but suboptimal vegetation cover, indicating moderate productivity. These areas are relatively favorable for rainfed farming, yet achieving maximum yield potential requires efficient resource use and the implementation of specific agro-technical interventions.
4. High-Vegetation Areas: These are zones where the vegetation cover is well developed and soil fertility remains high. Such areas represent the most productive rainfed lands and are essential for maintaining ecosystem stability. Continuous monitoring of these territories helps preserve soil health and ensure long-term agricultural sustainability.

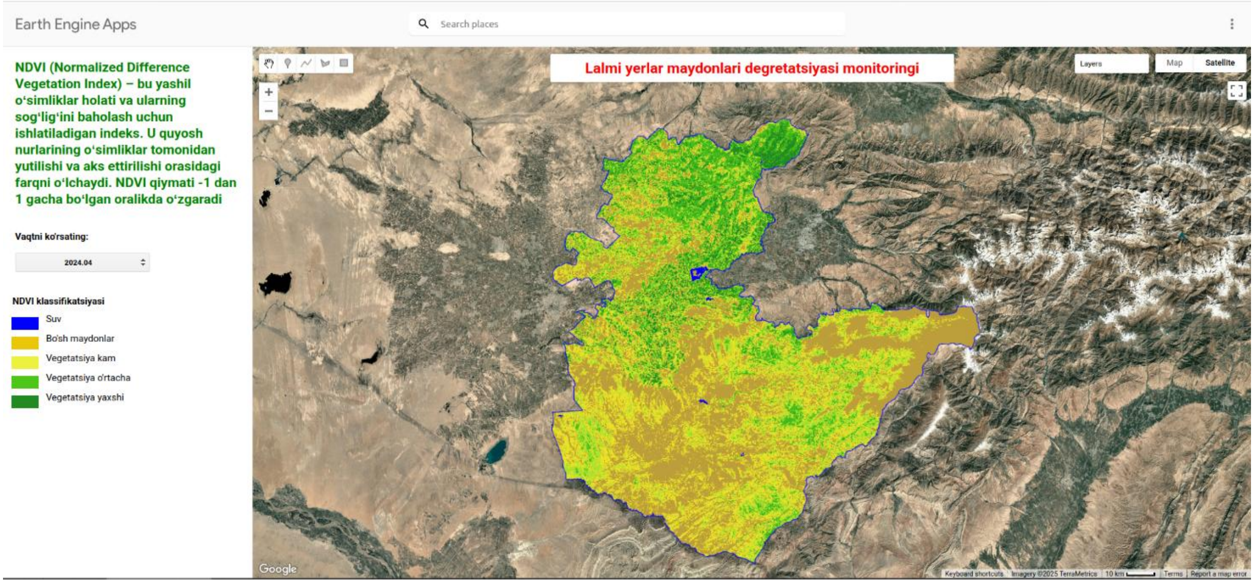

Figure 5. Monitoring of Vegetation Cover in Rainfed Land Areas During the Spring Season Using the Google Earth Engine (GEE) Platform

Through the use of the Google Earth Engine (GEE) platform, accurate assessment results are obtained for each of these categories, and the resulting data play a crucial role in shaping agricultural policies, preventing soil erosion, and increasing crop productivity. By conducting analyses based on satellite data, it becomes possible to observe and effectively manage the dynamics of vegetation cover in rainfed areas.

Thus, the Google Earth Engine technology serves as a reliable tool for monitoring vegetation cover, evaluating biomass and productivity, and ensuring sustainable land management in rainfed territories. In the future, this technology is expected to play an essential role in promoting the efficient utilization of land resources and supporting sustainable agricultural development.

Discussion

The findings of this research demonstrate that the integration of remote sensing (RS) and Google Earth Engine (GEE) technologies provides an efficient, scalable, and accurate approach to monitoring the degradation of rainfed (lalmi) lands. The proposed web-based system, developed within the GEE cloud platform, effectively automates the processes of data acquisition, NDVI computation, and visualization, allowing real-time observation of vegetation dynamics across vast and ecologically diverse regions.

The NDVI-based assessment results indicate significant spatial variability in vegetation health and productivity among the selected districts of Kashkadarya region - particularly in Ko‘kdala, Dehqonobod, Qamashi, G‘uzor, and Chiroqchi. Seasonal analysis revealed that vegetation cover tends to be highest during the spring and lowest during the late summer and autumn months, which corresponds with precipitation patterns and soil moisture availability. These results align with the findings of FAO (2023) and Yusupov (2023), who emphasize the strong correlation between rainfall distribution and vegetation performance in Central Asia’s arid ecosystems.

One of the most significant contributions of this study lies in its demonstration of the advantages of cloud-based geospatial analysis. Compared to conventional offline GIS systems, the GEE environment allows large-scale data processing without high hardware requirements, offering open access to datasets such as Landsat 8/9, Sentinel-2, and MODIS. This advantage enables both researchers and policymakers to conduct continuous and evidence-based environmental monitoring. Similar conclusions were drawn by Gorelick et al. (2017) and Azzari & Lobell (2017), who highlighted GEE’s transformative potential for real-time environmental analysis.

Furthermore, the automated classification model developed in this study successfully identified four major vegetation categories — bare areas, low vegetation, moderate vegetation, and high vegetation zones - consistent with the degradation patterns observed by Wessels et al. (2012) in arid ecosystems. This classification provides valuable insights into soil erosion risk, vegetation density, and potential restoration priorities. The spatial distribution maps generated through the GEE platform allow regional authorities to pinpoint critical degradation zones and implement targeted interventions.

From a practical standpoint, the integration of NDVI time-series analysis with meteorological and soil data offers a reliable foundation for sustainable agricultural planning. The study's outcomes confirm that continuous satellite-based monitoring supports early detection of ecological stress, optimization of crop rotation practices, and prevention of land misuse. The ability to cross-correlate vegetation indices with climate data — particularly rainfall and temperature - enables more informed decision-making in agricultural management, as also noted by Hansen et al. (2013) and Karimov & Turaev (2022).

Moreover, the research underlines the necessity of institutionalizing remote sensing–based monitoring systems within national environmental policy frameworks. For countries like Uzbekistan, where degradation in rainfed lands is both widespread and accelerating, adopting digital and cloud-based tools can significantly improve the efficiency and transparency of ecological governance. The automation of degradation assessment not only reduces human error and operational costs but also ensures data consistency and replicability — aspects crucial for long-term sustainability monitoring.

In summary, the discussion highlights that GEE-enabled NDVI monitoring is a cost-effective, scientifically grounded, and technologically advanced method that bridges the gap between research and policy. By facilitating continuous, data-driven observation of vegetation health and soil condition, this approach offers a strong foundation for developing adaptive land management strategies, early warning systems, and resilience-oriented agricultural policies in Uzbekistan's arid regions and beyond.

Conclusion

Today, due to climate change, declining water resources, unsustainable land use, and intensive agricultural pressure, the degradation processes in rainfed lands are becoming increasingly severe. Under such conditions, identifying degraded areas through the Normalized Difference Vegetation Index (NDVI), analyzing their vegetation activity over time, and monitoring restoration dynamics have become essential for ensuring ecological sustainability.

The Google Earth Engine (GEE) platform provides an efficient, large-scale, and reliable means of conducting these analyses. Its extensive database of satellite imagery, cloud computing capacity, and interactive visualization tools create a powerful environment for the calculation and analysis of NDVI indices. By using NDVI indicators, it becomes possible to perform precise and dependable assessments of soil fertility, vegetation density, plant health, and the extent of land degradation.

Therefore, NDVI computation via GEE is valuable not only for scientific research but also for practical environmental monitoring, resource management, and strategic planning for sustainable agriculture. Utilizing this technology enables us not only to identify existing environmental problems but also to address them promptly, conserve natural resources, and take meaningful steps toward creating a sustainable environment for future generations.

In essence, the integration of NDVI and GEE represents a modern, scientifically grounded, and ecologically effective approach that plays a critical role in preventing land degradation and developing restoration strategies for rainfed ecosystems.

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