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Multi-faceted analysis of land use impact on rangeland health: Insights from normalized difference vegetation index assessment in stream, road, and mining areas

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ABSTRACT

This study provides an in-depth analysis of specific land use areas within a semi-arid rangeland region by utilizing the normalized difference vegetation index (NDVI). The stream areas, local roads, main roads, and rock mining areas were subjected to NDVI analysis, revealing distinct vegetation health patterns. The stream areas, encompassing a 10-meter buffer, exhibited NDVI values ranging from 0.0098 to 0.447, covering 0.3% of the total study area. NDVI values for local roads (5 m buffer) ranged from 0.07 to 0.438, while main roads (10 m buffer) showed values between 0.017 and 0.172. In the rock mining areas, NDVI values varied at 10-meter and 20-meter buffer distances, with a polygon region indicating values from 0.012 to 0.276. The findings underscore the impact of specific land use practices on rangeland health and advocate for integrating NDVI techniques in monitoring and decision-making processes. The study also emphasizes the importance of selective management strategies to preserve healthy rangeland areas and mitigate the negative effects of degradation drivers, such as population density, grazing intensity, deforestation, unmanaged mining, and unplanned road networks. These insights contribute to of developing sustainable land use practices and ecological resilience in semi-arid rangeland ecosystems.

Keywords: rangeland, roads, streams, NDVI, health, remote sensing, vegetation.

INTRODUCTION

Uzbekistan currently boasts more than 23 million hectares of natural rangelands, playing a vital role in supporting the needs of the population by providing food, shelter, and other essentials. However, these rangelands are experiencing degradation, resulting in a low productivity range of 0.25 to 0.32 tons per hectare of dry matter [5, 8]. To address this challenge, the integration of field research techniques with geographic information systems (GIS) and remote sensing (RS) methods is considered a cost-effective and precise approach for sustainable plant resource management, preventing degradation, and improving rangeland health conditions. The adoption of decision-making processes based on RS and GIS enables more effective local and regional-level management of rangelands. Remote sensing, with its high spatial and temporal resolutions from various sensors, cost advantages, and compatibility with field data, has proven beneficial for rangeland monitoring. Consequently, there is a pressing need to assess the area's condition to provide meaningful information about the health status of the rangeland. Remote sensing data applications have been available since 2015, including the use of high-resolution multispectral scanner (MSS) Sentinel images [10]. Remote sensing has emerged as an accessible and efficient tool for evaluating the current condition of rangelands and monitoring vegetation health. The NDVI has proven valuable for researchers in assessing natural processes affecting rangeland conditions, offering insights into the ecological and health status of the vegetation. Traditional geobotanical methods for assessing large-scale rangelands are complicated, time-consuming, and expensive [11, 12]. Therefore, this study employs RS as a useful tool for mapping rangeland health conditions, focusing on developing modern, accurate, and fast techniques. These techniques not only determine the ecological and health status of rangelands but also provide recommendations for sustainable use. The study specifically concentrates on mapping rangeland health using NDVI derived from Sentinel 2 remote sensing datasets, with a case study in the foothill artemisia-ephemeral rangeland regions of Uzbekistan. The Sentinel-2 series is chosen for its user-friendly interface, high spatial resolution (10 meters), facilitating visualization and land feature identification, and a temporal dataset with a frequency of 5 days (2–3 days in mid-latitude) contributing to higher accuracy and performance compared to other open-access satellite images [9, 10]. Currently, Sentinel-2 provides surface reflectance products available for free download directly from the European Space Agency (ESA) hub, Copernicus Open Access Hub (COAH) (https://scihub.copernicus.eu). This strategic use of Sentinel-2 data is a crucial step in gathering methodological knowledge and experience, laying the foundation for designing a plan for the strategic and sustainable management of rangelands in Uzbekistan. The primary objective of the study is to showcase the significance and practicality of monitoring rangelands through the application of remote sensing technologies. In conjunction with demonstrating the importance and convenience of monitoring pastures using remote sensing, the study aims to identify and analyses the causes of degradation through the utilization of remote sensing methods.

MATERIAL AND METHODS

The research site is situated around Charlak and Tash-Bakal villages in the Kushrabat district of the Samarkand region, Uzbekistan (Fig. 1).

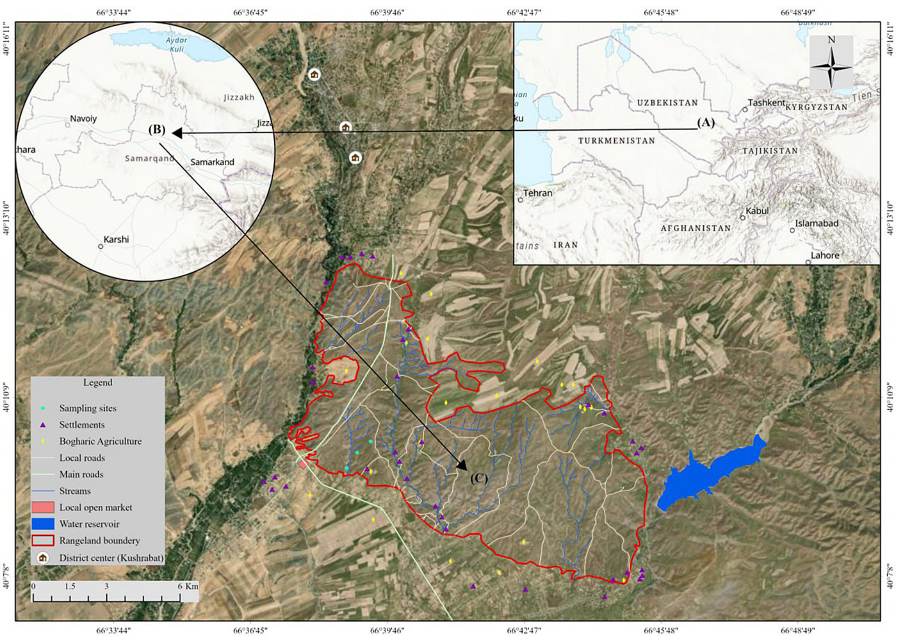

Figure 1. Map depicting the boundary of the study area with a black border line, highlighting Charlak and Tash-Pakal villages located within the Aktau foothill artemisia-ephemeral rangelands. Panel (A) represents the country (Uzbekistan), while panel (B) shows the Samarkand Region. ESRI Open Street Map contributors, HERE; Garmin, FAO, NOAA, USGS; Esri, CGIAR; USGS 2023.

This area falls within the semi-arid Aktau Foothill Rangelands Region, positioned at the periphery of the western Tien-Shan and interfacing with the Kyzyl Kum desert. The Aktau Mountain and foothill region span parts of the Navoi and Samarkand regions [13]. Specifically, the Samarkand region encompasses an area of 38.338 hectares, while the Kushrabat District accounts for 23.006 hectares of engaged rangeland [15]. Characterized as a dry basin filled with sandy and stony deposits, the landscape structure of the study area exhibits varying relief from low to high, locally referred to as "adyr" [2, 13]. Climatically influenced, the aboveground biomass (dry matter) of the foothill rangeland fluctuates from 0.8 to 1.0 ton/ha, dependent on prevailing conditions [7, 8]. The predominant soil type in the region is light sierozem, featuring a substantial gypsum layer and stone deposits. Soil conditions are characterized as barren, with very low organic matter content (less than < 1%) [3, 14]. The elevation in the research area ranges from 500 to 1200 meters above sea level. The history of rangeland use in the Aktau foothill region traces back to ancient times when the local population engaged in agricultural and farming traditions. Simultaneously, trade and crafts flourished in the region.

Remote sensing data

The current dataset for the study area, dated June 6, 2023, was procured from the Copernicus Center hub of the European Space Agency (ESA). This dataset, derived from the Sentinel-2 (MSI) mission with atmospheric correction applied since 2017 (COAH), enhances user efficiency. It is noteworthy that the image from this period highlights *Artemisia diffusa* within semi-shrub rangeland areas affected by anthropogenic activities (Fig. 1 and Fig. 2). In essence, the utilization of Sentinel-2 data allows users to extend the analysis period rather than solely planning for it. The objective of the project study is to leverage Sentinel-2A multispectral instrument (MSI) images for analysis. The entire study region encompasses scenarios captured by the Sentinel-2A (MSI) instrument. A single cloud-free image (0.0% cloud cover) from Sentinel-2, level-L1C, was obtained from COAH for the summer season.

Vector dataset collection for the study area was carried out due to the absence of local datasets. This involved manually collecting vector data from Google Earth using ArcGIS Pro 2.6, wherein the study area boundaries were delineated. Following the delineation of the study boundary, information on other land use systems within the study area, such as cropland, streams, settlements, orchards, main roads, local roads, mining areas, and local markets, was also manually delineated using ArcGIS Pro (Fig. 1 and Fig. 2). This method allowed for the creation of a comprehensive vector dataset for the study, despite the initial lack of local datasets.

Project methodology flowchart

Obtaining cloud-free and atmospherically corrected Sentinel-2 images

Utilize tools such as Sentinel Application Platform (SNAP) or Atmospheric Correction for the OLCI (ACOLITE) software. Process Sentinel-2 images to remove atmospheric effects, including aerosols and water vapor, and correct for cloud effects.

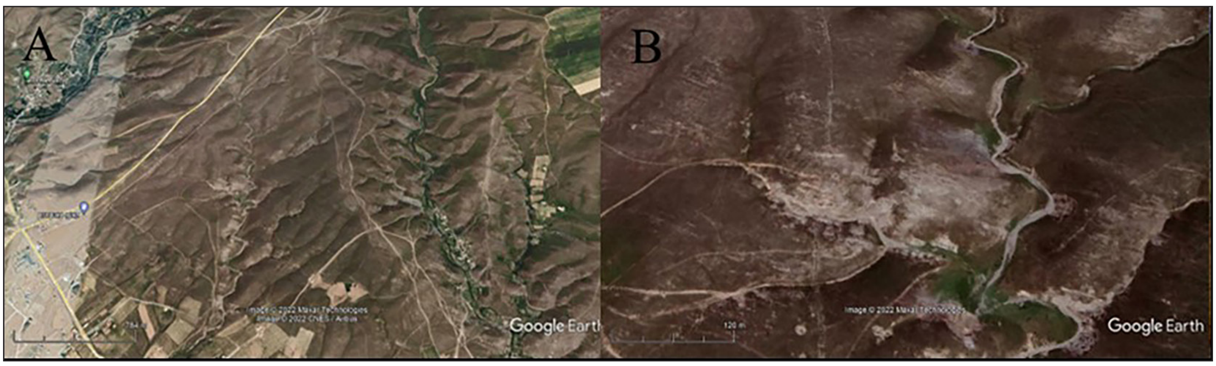

Figure 2. Local roads (A) and the mining area (B) are visible, highlighting regions with rock excavation. Google Earth Pro (2023).

Image processing using ArcGIS Pro

The Sen2Cor plug-in was employed for acquiring surface reflectance data, as Sentinel-2 Level 1C data only corrects for top-of-atmosphere reflectance (TOA Top-of-Atmosphere). Sen2Cor serves as a processor for Sentinel-2 Level 2A product production and formatting, addressing cirrus and terrain correction in addition to the initial TOA correction. The ESA's Sen2Cor plug-in, integrated with SNAP toolbox version 02.08.00, facilitated the transformation of downloaded L1C-level top-of-the-atmosphere (TOA) reflectance data into L2A-level surface reflectance data. Following image pre-processing, the study area's satellite image boundary was delineated, focusing specifically on the artemisia-ephemeral rangeland area. Other land use systems, such as farmland, orchards, streams, and settlement areas, were removed using the spatial analysis toolbox to refine the analysis. Further, for a detailed examination of the rangeland and an exploration of the influence of anthropogenic and natural factors, three anthropogenic factors (main road, local roads, and mining) and one natural factor (streams) were selected for additional image analysis.

To conduct this analysis, the following steps were taken in ArcGIS Pro

Extraction by mask

Utilized the spatial analysis tool to remove non-rangeland features by extracting by mask.

Buffering analysis

Employed the buffering tool in ArcGIS Pro for further analysis of anthropogenic and natural factors. For mining site analysis, a 1-kilometer by 1-kilometer polygon was created, and the center of the mining area was buffered by 10 and 20 meters. Main roads (10 meters), local roads (5 meters), and streams (10 meters) were buffered for detailed analysis of their impact on the rangeland condition. These procedures ensure a focused analysis of the artemisia-ephemeral rangeland, shedding light on both natural and anthropogenic factors influencing its condition. The combination of Sentinel-2 data and ArcGIS Pro tools provides a robust framework for comprehensive landscape analysis.

Labelling the resulting clusters

Label clusters based on their spectral characteristics and field observations. Identify and differentiate land cover and vegetation types in the study area. Assess the health and condition of identified land cover types.

NDVI calculation

The calculated *NDVI* values (Equation 1) for different areas of interest, such as the total rangeland area, mining area, streams, and roads, can facilitate the identification of potential impacts on vegetation health and condition, particularly related to mining activities and road construction.

$$NDVI = \div\frac{(Near\ infrared\ (8\ band\ )+Red\ (band\ 4))}{(Near\ infrared\ (8\ band)-Red\ (band\ 4))} \quad (1)$$

where: the *NDVI* calculation is appropriately tailored for Sentinel-2 imagery, where *band* 4 corresponds to the *red band*, and *band* 8 corresponds to the *near-infrared band*.

Table 1. NDVI values for the buffered areas represent vegetation health and density within designated zones surrounding key features or focal points

Buffered area	Max	Min	Mean	Standard deviation	Area (ha.)	(%)
The main road buffered at a 10 m distance	0.169	0.017	0.084	0.028	14.5	0.3
Local road buffered at a 5 m distance	0.429	0.021	0.092	0.036	65.9	1.3
Streams buffered at a 10 m distance	0.438	0.010	0.128	0.057	58.3	1.2
Total rangeland area within the study boundary	0.470	-0.074	0.100	0.036	5058.2	100
Rock mining polygon area: 1000 m × 1000 m						
Buffer distance of 10 m from the rock mining point	0.126	0.018	0.053	0.015	1.16	1.16
Buffer distance of 20 m from the rock mining point	0.246	0.018	0.062	0.021	4.6	4.6
Total buffered mining polygon area measuring 1000 m × 1000 m	0.270	0.012	0.081	0.206	100	100

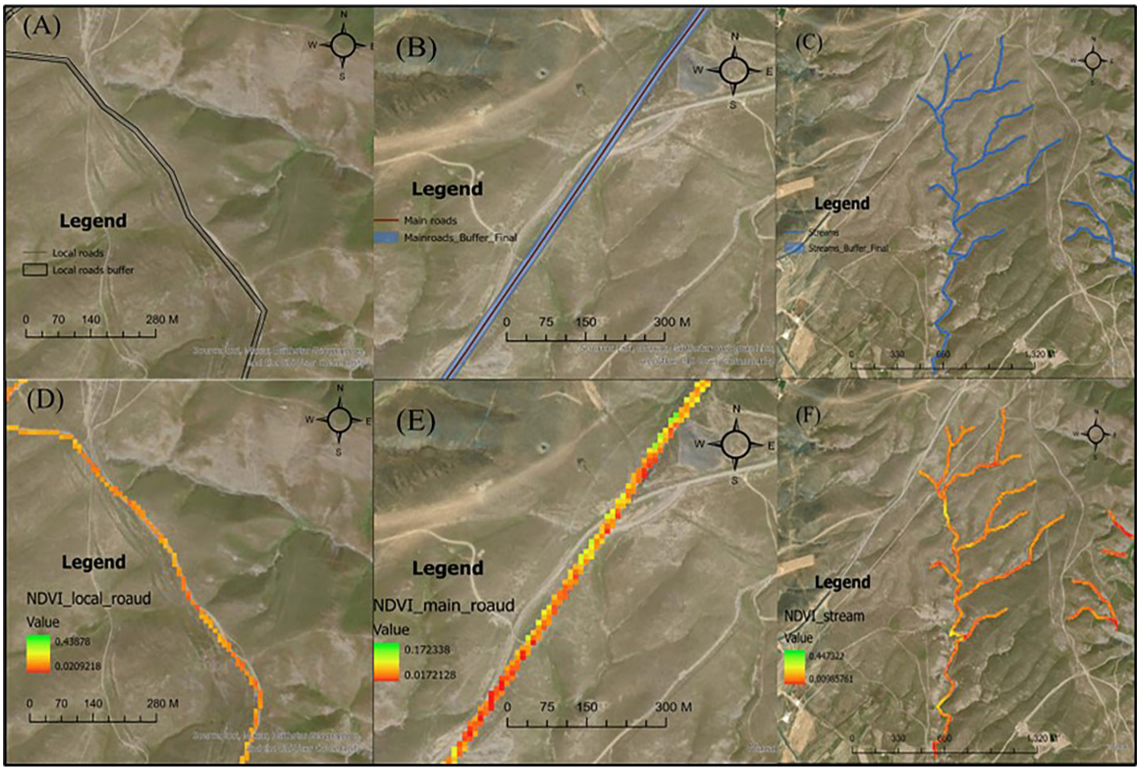

Figure 3. Local road with buffer (A), main road with buffer (B), stream with buffer (C), and corresponding NDVI values for the local road (D), main road (E), and streams (F)

RESULTS AND DISCUSSION

Results

Stream area analysis

The NDVI values within the stream areas exhibited a range of 0.010 to 0.438, as detailed in Table 1 and Figure 3. The 10-meter buffered stream covered an area of 58.3 hectares, constituting 1.2% of the overall study area.

Road area analysis

In the study, NDVI values were extracted from both the buffered local road (5 m) and the main road (10 m). For local roads, NDVI values ranged from 0.021 to 0.429, while for main roads, the range was 0.017 to 0.169 within the study area Table 1 and Figure 3).

Mining (rock) area analysis

Within the rock mining area, NDVI values varied from 0.015 to 0.126 at a 10-meter buffer distance and from 0.018 to 0.246 at a 20-meter buffer distance (Table 1). The 1000 m² rock mining polygon region exhibited NDVI values ranging from 0.012 to 0.270 (Table 1 and Figure 4).

Discussions

The findings of the case study indicate that the primary drivers of rangeland degradation include a high population density, intensive grazing, deforestation, unmanaged stone mining, and the presence of unplanned interconnected local roads. Considering these factors, implementing integrated rangeland restoration becomes imperative, emphasizing the need for participatory land use systems. Additionally, the swift assessment of rangeland health through the NDVI technique proves crucial. This method facilitates continuous monitoring of rangeland health, enabling decision-makers to take proactive measures to mitigate negative impacts on the rangeland. The results of the classification reveal areas of high stress and those with healthy vegetation within the rangeland. This information is instrumental in implementing a selective management system, avoiding stress-inducing factors, and introducing protective measures to conserve areas with healthy rangeland. Overall, these measures contribute to the conservation and protection of rangelands, ensuring their sustainable use and promoting ecological resilience. The analysis of specific land

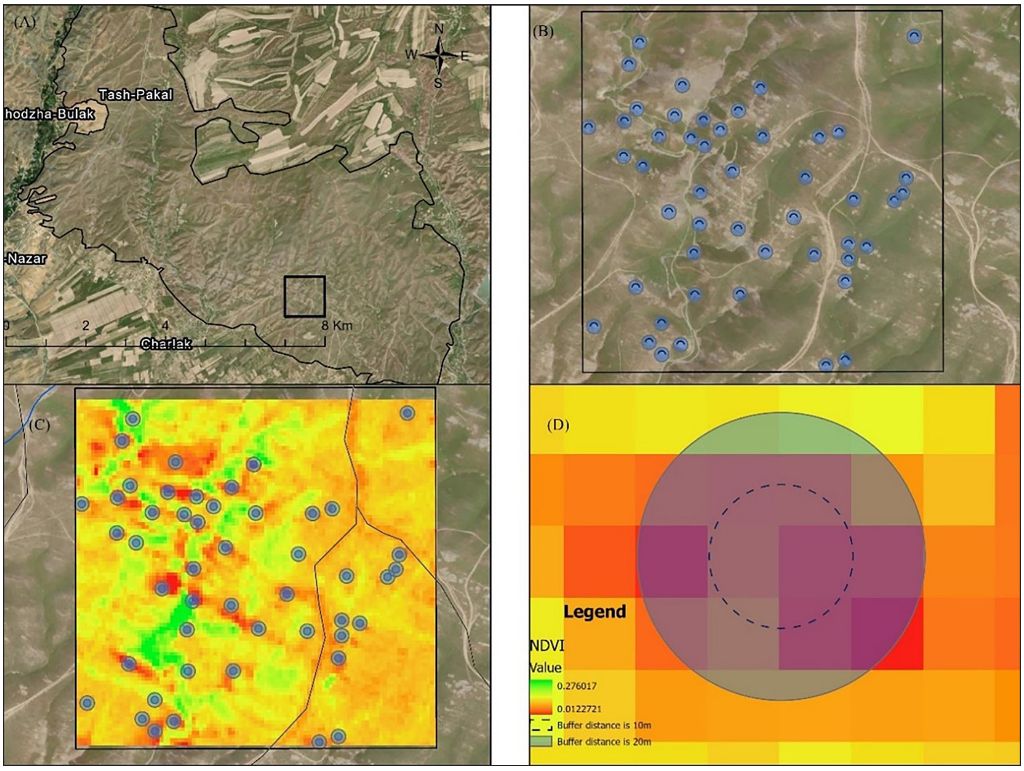

Figure 4. Study area (A), rock mining polygon (1000 × 1000 m) (B), NDVI values within the buffered rock mining polygon (C), and NDVI values at buffer distances of 10 m and 20 m from the rock mining point (D)

use areas within the semi-arid rangeland region, focusing on stream areas, roads, and rock mining zones, sheds light on the nuanced relationships between land use practices and vegetation health, as indicated by the NDVI values.

Stream area analysis

The NDVI values within stream areas exhibited a diverse range, suggesting varying degrees of vegetation health. The 10-meter buffered main road, constitutes a small percentage (1.2%) of the overall study area reflected specific ecological conditions. The observed NDVI values highlight the importance of riparian zones in influencing vegetation health, with potential implications for water quality and ecosystem dynamics.

Road area analysis

Extracting NDVI values from both local and main roads provided insights into the impact of road infrastructure on vegetation health. The diverse range of NDVI values for local and main roads indicate differential effects on the surrounding vegetation. Higher NDVI values for local roads may be indicative of vegetation adaptation or less disruption compared to main roads. This emphasizes the need for careful road planning to minimize ecological impact.

Mining (rock) area analysis

The analysis of rock mining areas revealed variable NDVI values at different buffer distances, suggesting spatial heterogeneity in vegetation health. The 1000 m² rock mining polygon region exhibited a range of NDVI values, signifying the potential impact of mining activities on surrounding vegetation. The observed variability underscores the importance of buffer distances in capturing the extent of influence on vegetation health.

Primary drivers of rangeland degradation

The discussion emphasizes the identified primary drivers of rangeland degradation, including high population density, intensive grazing, deforestation, unmanaged stone mining, and unplanned road networks. These factors collectively contribute to the alteration of vegetation cover and land use patterns, leading to ecological imbalances and degradation.

Importance of integrated rangeland restoration

The findings underscore the urgency of implementing integrated rangeland restoration strategies.

The discussion emphasizes the significance of participatory land use systems, highlighting the need for collaboration between stakeholders to address the identified drivers of degradation effectively.

Role of NDVI technique in rangeland health assessment

The swift assessment of rangeland health through the NDVI technique emerges as a crucial component of the study. Continuous monitoring using NDVI enables decision-makers to proactively respond to negative impacts on the rangeland, supporting sustainable land management practices.

Selective management system

The classification results, distinguishing areas of high stress from those with healthy vegetation, offer valuable information for implementing a selective management system. This system aims to avoid stress-inducing factors and introduce protective measures, contributing to the conservation and sustainable use of rangelands.

In summary, the discussion highlights the intricate relationships between specific land use practices and vegetation health, providing insights that are crucial for informed decision-making and sustainable rangeland management. The study underscores the need for holistic approaches, incorporating ecological considerations and active participation from stakeholders to ensure the long-term health and resilience of semi-arid rangeland ecosystems.

CONCLUSIONS

In conclusion, the comprehensive analysis of specific land use areas within the semi-arid rangeland region, employing the NDVI, has provided valuable insights into the factors influencing rangeland health. The examination of stream areas, local roads, main roads, and rock mining zones revealed distinct NDVI patterns, underscoring the impact of various land use practices on vegetation health. Stream areas, characterized by NDVI values ranging from 0.010 to 0.438 within a 10-meter buffer, constituted 1.2% of the overall study area. The road area analysis, encompassing both local roads (5 m buffer) and main roads (10 m buffer), exhibited varied NDVI values, highlighting the differential impact of road infrastructure on vegetation health. Notably, the mining (rock) area analysis portrayed a range of NDVI values, emphasizing the varying degrees of impact on vegetation within different buffer distances. The 1000 m^2 rock mining polygon region exhibited NDVI values ranging from 0.012 to 0.270. The overarching findings of the case study underscore the significant role of specific land use practices, including high population density, intensive grazing, deforestation, unmanaged stone mining, and unplanned road networks, as primary drivers of rangeland degradation. Consequently, the study advocates for the implementation of integrated rangeland restoration strategies, emphasizing participatory land use systems to address these challenges. Moreover, the swift assessment of rangeland health through the NDVI technique is identified as a crucial tool for continuous monitoring. This approach enables decision-makers to proactively respond to negative impacts, facilitating the conservation and protection of rangelands. The results of the classification, which distinguish areas of high stress from those with healthy vegetation, inform the implementation of a selective management system. This system aims to avoid stress-inducing factors and introduce protective measures, ultimately contributing to the sustainable use and ecological resilience of rangelands. Overall, these insights provide a foundation for informed decision-making and sustainable land management practices in semi-arid rangeland ecosystems.

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