Space remote sensing for monitoring seasonal dynamics of grasslands in high-altitude zones in Armenia

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The study, effective management, and rational use of mountain grasslands are becoming increasingly important due to the threat of natural and human-induced degradation. In Armenia, this remains a critical issue that requires comprehensive monitoring and consistent management. The application of remote sensing provides an opportunity to detect stressed and harmed vegetation, which in turn helps to assess the state of biomass. In this study, remote sensing data were used to determine the state of pasture vegetation, which is an important forage base, in conditions of vertical zonation in a small area. In addition, the data were used to develop a rational grazing regime for pasture users. The results show that incorrect grazing practices are observed in certain landscape zones. Livestock breeding is mainly concentrated in the meadow-steppe zone, which can lead to overgrazing. Meanwhile, other zones are underutilized due to premature livestock relocation. This study aims to use remote sensing to assess the vegetation condition of grasslands located in altitudinal landscape zones during the growing season and, based on this, help users optimize grazing, organize rational grassland management, and avoid overgrazing.

1. INTRODUCTION

Grasslands are renowned for their significant economic and ecological value worldwide, particularly in mountainous regions where arable land is scarce, and crop cultivation is limited. They play a crucial role in addressing several food security challenges. However, unregulated and improper use of grasslands and pastures, without adherence to basic grazing standards, leads to vegetation loss, disruption of plant community balance, and reduced productivity. Ultimately, this results in grassland degradation (Ayvazyan, G. and Asmaryan, S., 2023). Such degradation causes a decline in both vegetation and animal productivity. Consequently, studying and monitoring the condition of grasslands has become a priority.
The Republic of Armenia (RA) is no exception to this pressing issue. As a mountainous country, Armenia exhibits distinct vertical landscape zoning. Its diverse landscape zones, ranging from arid semi-deserts to alpine regions (500–3,400 m), are characterized by pronounced vertical zonation (extending over 26 km upwards) of soil and vegetation cover. According to Tovmasyan (2019), over half of Armenia’s farmland is covered by grasslands, which supply more than two-thirds of the nation’s forage needs. However, harsh natural conditions and anthropogenic factors, such as overgrazing and unsystematic harvesting, have significantly contributed to the degradation of these ecosystems.
The ongoing advancement of remote sensing technologies has made them essential tools for monitoring changes over vast areas (Andreatta et.al, 2022). These technologies enable the assessment of dynamic environmental changes and facilitate effective management and planning of agricultural lands (Houborg and F. McCabe, 2016). In agriculture, remote sensing provides various sensors and technologies to collect data on crops, plants, and other key agricultural factors (Wang et. Al, 2022). This information plays a vital role in decision-making towards improving farming efficiency. Common remote sensing methods include satellite imagery, aerial photography, drones, and ground-based sensors. By analyzing spectral signatures, which differ between healthy and stressed plants, remote sensing helps detect degraded areas in grasslands (Yuan et.al, 2022).
Despite its potential, remote sensing is not yet actively and widely used to study and monitor natural mountain grasslands in Armenia. One of the reasons is a terrain complexity, which creates variations in natural zones at short distances. Some studies have been conducted on creating a grassland inventory through RGB image processing and mapping and developing seasonal rotational grazing schemes for farmers in more than 70 rural communities in Armenia within the framework of the CARMAC project, funded by the World Bank (Asmaryan & Mezhunts, 2011).This project highlights the necessity for advanced and efficient tools to assess and monitor the dynamics of natural mountain grasslands, considering their ecological complexity and the challenges of traditional field methods. However, despite the importance of this work, it needs to be supplemented with remote sensing data and tools. Remote sensing, with its ability to analyze spectral vegetation indices provides a cost-effective and largescale approach to overcome these limitations by enabling the continuous observation of vast and inaccessible areas, capturing variations in vegetation cover, biomass productivity, and land use changes for a long time. In turn, vegetation indices enable not only to observe vegetation, but also to assess its condition, as well as to track seasonal according to high zoning. Thus, this study aims to estimate the condition of plant communities using remote sensing under natural and high-zonal conditions to determine resource capacity and grazing load regimes. This action, will help to control grazing, manage livestock timely movement according to vegetation pick in every zone and avoid overgrazing.

2. MATERIALS AND METHODS

2.1 Study Area

Armenia is a mountainous country in the Caucasus region. Its landscape zones vary over short distances depending on elevation (500–3,400 m). Armenia occupies an area of 29,800 square kilometers and has an average altitude of 1,700 meters above sea level. Due to its rugged terrain, 9.9% of the country's territory is located at an altitude of up to 1,000 m above sea level, 76.6% at 1,000–2,500 m, and 13.5% at above 2,500 m (Tovmasyan, 2019). According to the Real Estate Cadaster Committee under the Armenian Government (Tepanosyan, 2019), more than 68% of the country's total land area is classified as agricultural land, with over half of it (57%) consisting of natural grasslands and pastures. The study was focused on the pastures and grasslands of the Nerkin Sasnashen rural community in the Aragatsotn district of Armenia, covering 4,660 hectares, which is characterized by diverse land cover, including vegetation, bare soil, water bodies, and rocky deserts. The community is located on the southwestern slope of the Aragats volcanic shield (40°21′23″ N, 43°59′31″ E), extending from north to south (Tepanosyan, 2019). In the study site **(Figure 1)**, the landscape is composed of semi-desert (500–1,000 m), dry steppe (1,000–1,400 m), steppe (1,400–2,300 m), mountain–meadow–steppe (2,300–2,600 m), subalpine highland (2,400–2,800 m), and alpine (2,880–3,400 m) zones, which include 20 distinct grassland sites (Tovmasyan, 2019).

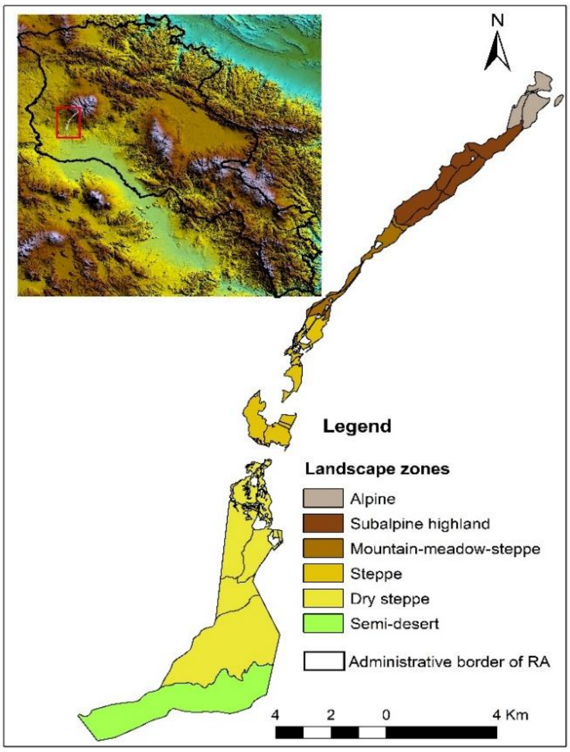


Figure 1. Landscape zones of Nerkin Sasnashen community grasslands.

2.2 Data

Daily scenes of Planet Scope satellite images with a spatial resolution of 3 meters covering the period May to August 2023 were used and a daily temporal resolution, obtained from the standard Planet Analytic Product (Radiance) (Planet Imagery Product Specifications, 2023). All downloaded scenes were previously processed to top-of-atmosphere (TOA) reflectance and atmospherically corrected to surface reflectance. The further processing was conducted in the ArcGIS Pro environment. The scenes were filtered on cloud cover and only 9 scenes with less than 5% cloud cover were selected. All images with the cloud cover were not considered in the study which significantly reduces the number of days for observation, especially at the beginning of the growing season. Data on the grazing periods (Fig.2) was provided by the Local Authorities of Nerkin Sasnashen rural community was also incorporated for the further analysis. Vegetation periods and vegetation community of each landscape zones were observed (National Atlas of Armenia, 2007).

2.3 Methods

To address the characteristics and challenges of the landscape while ensuring a comprehensive evaluation of vegetation condition which is essential for grazing planning, five indices were selected (NDVI, GNDVI, GLI, SAVI, GSAVI). All scenes of Planet Scope data were processed on vegetation indices based on Near-Infrared (NIR), Red, Green, and Blue spectral bands (Table1).

Index	*Index name*	*Equation*	*Values*	*Citation*
NDVI	Normalized difference vegetation index	(NIR-Red) / (NIR+Red)	-1 to 1	Zhang et al., 2019
GNDVI	Green normalized difference vegetation index	(NIR-Green) / (NIR+Green)		Gitelson et al. 1996
GLI	Green leaf index	(2*Green-Red-Blue)/(2*Green+Red+Blue)		Xu et al, 2022
SAVI	Soil adjusted vegetation index	1.5*(NIR-Red) / NIR+Red+0.5		Huete, 1988
GSAVI	Green soil adjusted vegetation index	1.5*(NIR-Green) / NIR+Green+0.5		Ren et. al, 2018

Table1. Applied spectral vegetation indices

NDVI is a standardized method for assessing vegetation health. GNDVI**,** which is more sensitive to chlorophyl content effectively utilizes the green channel to estimate vegetation cover with enhanced accuracy (Gitelson et al. 1996, Zhang et al., 2019). The effectiveness of NDVI may be restricted (Wang et. Al, 2022) in areas with sparse vegetation due to significant soil background interference in estimating green aboveground biomass (Ren and Zhou, 2014). To mitigate this issue, SAVI incorporating a correction factor to minimize soil background influences vegetation cover is low (Huete, 1988) and better accounts for the effect of soil brightness (Xu et.al, 2021). GSAVI, have been developed to enhance accuracy by reducing noise and soil-related distortions affecting NDVI (Ren et. al, 2018). GLI is accepted to effectively distinguish vegetation from the surrounding background, also it is particularly useful for identifying individual plants against varying backgrounds (Xu et al, 2022, Bassine et al., 2019). Мореовер, in the Global Mapper environment, a physical-geographical profile of the study area was created based on elevation levels from 500 m to 3,400 m, depicting vertical landscape zones and the dominant forage vegetation species there. The profile also includes the vegetative periods of the natural zones, remote sensing data of the vegetation season by day of the month, and grazing periods, which are provided by the rural community and organized for each zone (Figure 2).

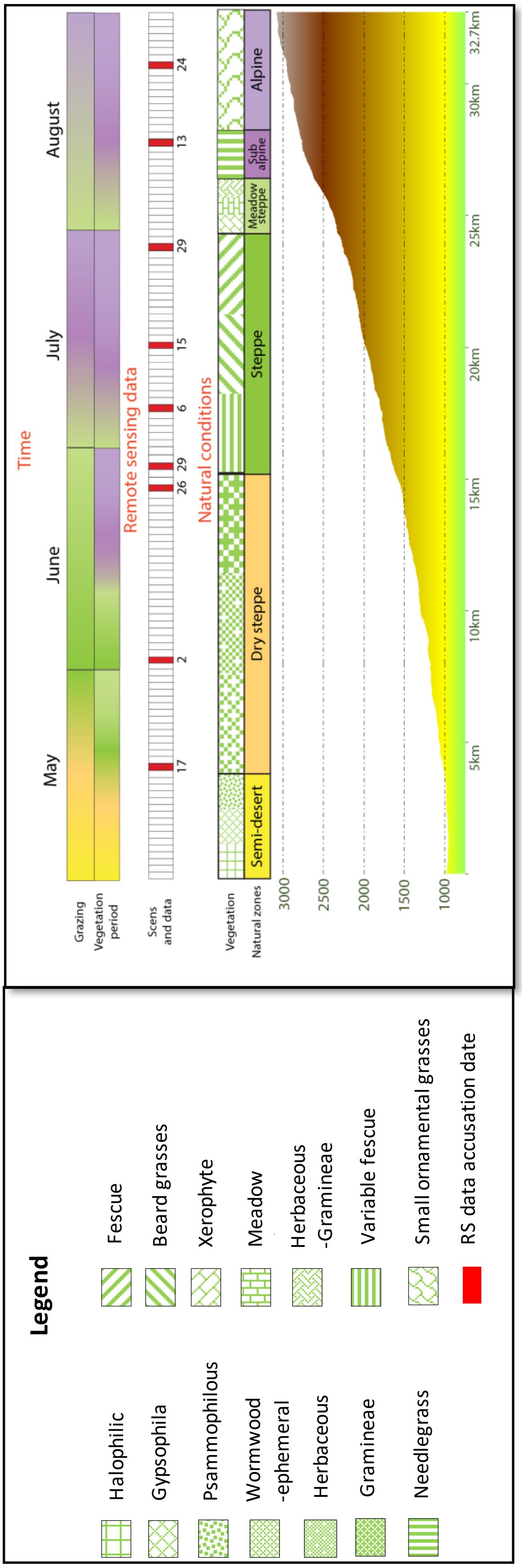
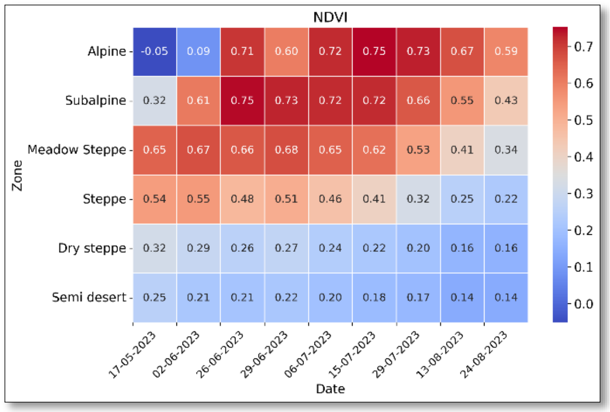


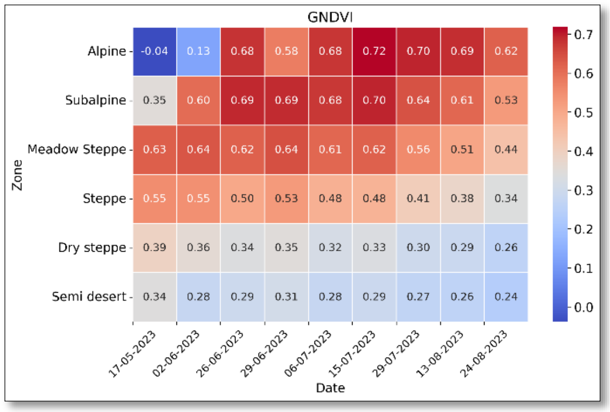
Figure 2. The diagram showing the complex physiographic profile, RS data date, grazing and vegetation periods, and dominated vegetation species

3. RESULTS

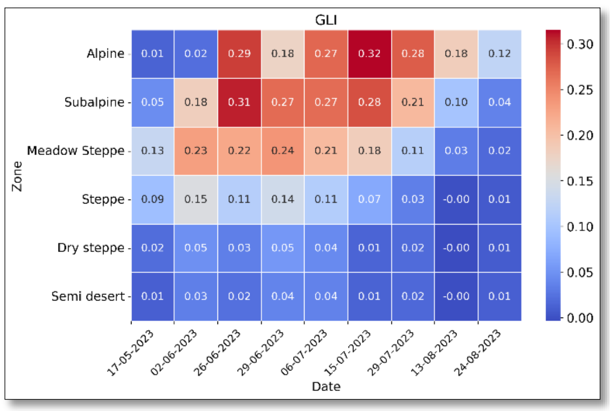
Vegetation state of each landscape zones based on above mentioned vegetation indices represented in Figure 3 (a, b, c, d, e). According to the NDVI values, as of May 17, the vegetation peak was observed in the Steppe and Meadow Steppe zones, with values of 0.54 and 0.64, respectively. In the Steppe zone, similar values were recorded on June 2. High NDVI values were also observed in the Meadow Steppe (0.67) and Subalpine (0.60) zones. From June 26 to August 13, NDVI values above 0.5 were recorded in the Meadow Steppe, Subalpine, and Alpine zones. In the Alpine zone, the vegetation period extended until August 24, reaching 0.58.



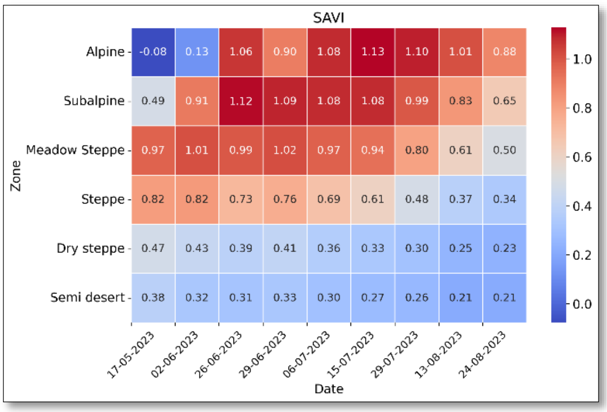
a)



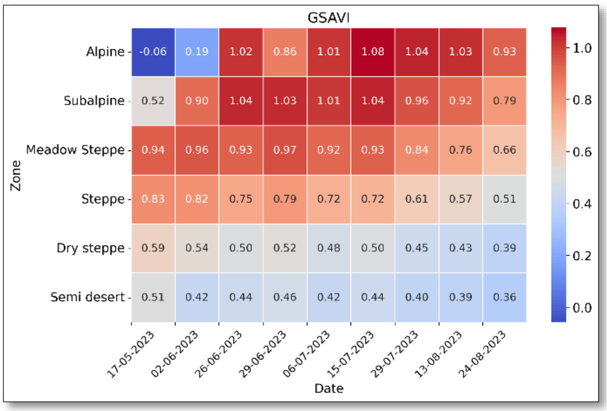
b)



c)



d)



e)

Figure 3. The heatmaps of values of vegetation indices for landscape zones of Nerkin Sasnashen grasslands: a) NDVI, b) GNDVI, c) GLI, d) SAVI, e) GSAVI

The GNDVI, which is more sensitive to chlorophyll content, confirms that in the Steppe zone, the vegetation period lasts from May until the end of June. In the Meadow Steppe zone, vegetation extends until August 13, while in the Subalpine zone, high values were recorded starting from June 2 and continued until August 28. Lower GNDVI values were observed in the Semi-desert, Dry Steppe and Alpine zones. The GLI, which was used to distinguish vegetation from surrounding land cover, showed values closely matching NDVI trends across vertical landscape zones. Based on this, a similar grazing schedule is expected. To reduce the influence of soil background on NDVI values, the SAVI and GSAVI were applied, resulting in slightly different patterns. According to SAVI values, dense vegetation was observed in the Steppe and Meadow Steppe zones starting from May 17. In the Steppe zone, this lasted until July 15, after which it gradually decreased. In the Meadow Steppe zone, high vegetation persisted until August 24. In the Subalpine and Alpine zones, dense vegetation was recorded from June 2 until August 24. Based on these findings, grazing in the Steppe zone can be extended until July 15, while in the Meadow Steppe zone, it could start as early as June 2, rather than in July. According to GSAVI values, dense vegetation was observed in the Semi-desert zone only on May 17, after which it gradually declined. In the Dry Steppe zone, the vegetation period lasted until June 29. In the Steppe and Meadow Steppe zones, vegetation continued until August 24. The Subalpine zone exhibited high GSAVI values from June 2 to August 24, while in the Alpine zone, high values were recorded from June 26 to August 24.

4. DISCUSSION

The results from this study indicate that the satellite imagery with high spatial resolution have the potential to assess pasture productivity and can be used for field research and management of small and medium-sized pastures. Several vegetation spectral indices were used. NDVI and its derivatives are used as a standard index in many studies to determine the health of pasture vegetation (Reinermann et. al, 2020). Based on the NDVI classification scheme Table 2, which is adapted from ("Agricolus," n.d.) and was previously published in Ayvazyan G. and Asmaryan S. (2023), it can be concluded that the vegetation in the Alpine and Subalpine zones of the study area corresponds to average to high canopy cover. Therefore, based on NDVI data, grazing in the Alpine zone can continue until the end of August, rather than stopping in July as previously planned.

NDVI	*INTERPRETATION*
< 0.1	Bare soil
0.1 – 0.2	Almost absent canopy cover
0.2 – 0.3	Very low canopy cover
0.3 – 0.4	Low canopy cover, low vigour or very low canopy cover, high vigour
0.4 – 0.5	Mid-low canopy cover, low vigour or low canopy cover, high vigour
0.5 – 0.6	Average canopy cover, low vigour or mid-low canopy cover, high vigour
0.6 – 0.7	Mid-high canopy cover, low vigour or average canopy cover, high vigour
0.7 – 0.8	High canopy cover, high vigour
0.8 – 0.9	Very high canopy cover, very high vigour
0.9 – 1.0	Total canopy cover, very high vigour

Table2. Classification of NDVI values for agricultural lands

Unlike to NDVI, which is the most widely used index in remote sensing of grasslands, including mountain pastures for instance to study grasslands in mountain regions of Kirgizstan and Uzbekistan (Mamatkulov et al, 2024, Tomaszewska et al, 2021), attempts have been made to use other indices (SAVI, GSAVI, EVI) to assess the condition of vegetation and create an optimal grazing scheme.

The GLI index was successfully applied by Louhaichi et al., 2001 to manage grazing in a wheat field northwest of Portland, Oregon, and to identify overgrazed and undergrazed areas, resulting in a proposed optimal grazing regime. Here, values above 0.25 were observed in areas where there was no grazing, and values of 0.1-0.25 were observed in overgrazed areas. In the case of pastures in the Nerkin Sasnashen community, values above 0.25 are observed only in the Alpine and Subalpine zones, which may indicate undergrazing of these areas and overgrazing of other areas. However, it should be taken into account that the areas studied in the work are a mountain grassland, where vegetation is denser than in wheat fields, as well as natural factors due to the relief and mountainous location are more pronounced. Based on this, it can be said that in future works it is necessary to take into account the natural and climatic conditions of the area.

According to the grazing regime (Figure 2) data provided by the local community, grazing in different landscape zones is organized based on the vegetation growth period, following the natural progression of plant development. In the Semi-desert zone Grazing ends in the last days of April and the first half of May. By mid-May, it shifts to the Dry Steppe zone, and by the end of May, it moves to the Steppe zone. In June, grazing is conducted in the Steppe and Meadow Steppe zones, with the latter continuing to be grazed in July and August. In July, grazing is also organized in the Subalpine and Alpine zones, while in August, it is restricted to the Meadow Steppe and Subalpine zones.

Limitations and Future Considerations

Based on the obtained results, poor vegetation cover was observed in the Semi-desert and Dry Steppe zones, suggesting the need to analyze additional satellite images from March and April. This highlights a limitation of the study, as cloud cover during these months restricts available data. Therefore, it is necessary to consider images with higher cloud coverage to obtain a more complete seasonal picture, particularly for April and May. Additionally, integrating climatic data and in situ field measurements will be essential for further research, ensuring a more precise and comprehensive analysis in future studies.

5. CONCLUSIONS

The combination of the studied indicators allows to detect the consition of biomass in grasslands of different landscape zones. According to the behavior of the indices, depending on the season and altitude, there is an undergarzing in the Alpine and Subalpine zones, at the expense of the Steppe and Meadow steppe zones. Thus, this study is a good addition to the grazing schemes developed for the Nerkin Sasunashen community, for the optimal organization of the grazing process.

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