SATELLITE REMOTE SENSING FOR ASSESSING THE SPATIOTEMPORAL CHANGES OF THE ECOLOGICAL STATE OF THE AGRICULTURAL LANDS IN ARMENIA

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ABSTRACT

Proper management and monitoring of the ecological condition of natural feeders are crucial for both the economy and natural environments. Armenia is no exception, and addressing this issue requires comprehensive studies combining traditional methods with remote sensing technologies. Remote sensing in agriculture utilizes various sensors and technologies to collect data about crops, soil conditions, and agricultural parameters from a distance. This study focuses on the utilization of remote sensing, including satellite imagery, to assess the ecological state of grasslands and pastures in the Syunik administrative district of Armenia. Over a 22-year period (2000-2021), the study utilized Landsat series (5,7,8) multispectral optical images processed through Google Earth Engine (GEE) to analyze changes in the Normalized Difference Vegetation Index (NDVI) as an indicator of vegetation health. The results reveal favorable trends in vegetation health across the study regions, as indicated by consistently positive Z-values in the Seasonal Mann-Kendall test. While no significant trends were observed in some areas, others showed improvements in biomass conditions. This study provides valuable insights into the resilience and health of grasslands and pastures in the Sisian and Goris regions, offering a basis for targeted interventions and strategies to preserve these ecosystems for future generations.

1. INTRODUCTION

Unplanned, irregular use of grasslands and pastures without observing the basic norms of grazing leads to thinning of vegetation, disturbance of interrelation between vegetation elements, and reduction of pasture productivity, which afterward to degradation (Tovmasyan, 2019). Thus, studying, monitoring and proper management of the ecological state of the mountainous grasslands is becoming imperative because of the threat of degradation. Today, pastures and grasslands are under threat of degradation all over the world, which leads to disturbance of natural balance, a decrease of soil productivity, and consequently to decrease of plant and animal productivity. Therefore, it should be noted that the study, monitoring, and correct management of the ecological condition of pastures and grasslands are in the interests of both the economy and natural ecosystems (Tovmasyan, 2019). It is one of the key issues in Armenia as well and it requires large-scale studies combining traditional methods supplemented by remote sensing (RS) technologies (Muradyan et al., 2022).

Remote sensing in agriculture refers to the use of various sensors and technologies to collect data from a distance about crops, soil conditions, and other agricultural parameters. These data are crucial for making informed decisions and optimizing agricultural practices. Some common remote sensing techniques used in agriculture include satellite imagery, aerial photography, drones, and ground-based sensors. Remote sensing is used to identify stressed areas in pastures by capturing the spectral signatures of healthy plants that differ from those of damaged and stressed plants (Metternicht et al., 2010). The wavelengths of the electromagnetic spectrum used for remote sensing in agriculture cover only a small part of the spectrum. The visible range of the electromagnetic spectrum is from about 400 nm to about 700 nm. The color green, associated with plant health/activity, has a wavelength centered around 500 nm. Wavelengths in the infrared (IR) range are longer (up to about 25 µm) than in the visible range. The infrared range closest to the visible is near-infrared (NIR). Both visible and infrared ranges are used for remote sensing of agricultural land (Roy et al., 2016). The continuous development of remote sensing methods and geographic information systems (GIS) made them important tools that give an opportunity to observe the spatio-temporal changes for large territory, assess paces of change, and arrange appropriate managing (assessing the spatial-temporal changes) of agricultural lands. In the context of remote sensing, only visual processing of satellite images and mapping was carried out for pastures and grasslands. Also, for the first time, Garegin Tepanosyan developed and evaluated the method of assessing the degradation of grasslands through spectral analysis of satellite images (Tepanosyan, 2019). This study is the first attempt to assess the spatiotemporal changes of the ecological state of the biomass of grasslands and pastures of some rural communities of the Syunik administrative district (marz) of the RA based on satellite remote sensing data and technologies.

2. MATERIALS AND METHODS

2.1 Study area

The Republic of Armenia is a mountainous country. It covers an area of 29.8 thousand square kilometers and is located at an average height of 1700 m above sea level. 9.9% of the territory of the republic lies at an altitude of up to 1000m above sea level, 76.6% at an altitude of 1000-2500m, and 13.5% at an altitude of more than 2500m (Tovmasyan, 2019). Such variations in height complicate the development and management of areas, especially agricultural lands. According to the data of the Real Estate Cadastre Committee under the RA Government (Tepanosyan, 2019), more than 68% of the republic's land fund is agricultural land, more than half of which, 57%, are natural fodder, pastures, and grasslands, which have a great environmental and socio-economic importance. The study area includes the pastures and grasslands of Tsghuk, Spandaryan, Sarnakunk, and Akner, Khnatsakh, Khndzoresk, Khoznavar, Vaghatur, Verishen, Tatev, Harzhis rural settlements accordingly in Sisian and Goris administrative regions of Syunik district in 2000-2021, the most mountainous district of RA. These regions are located in the south of Armenia and are characterized by dry continental climate conditions (Tovmasyan, 2019).

2.2 Data

According to G. Metternich found that the Landsat series of multispectral optical images (MSS, TM, ETM +, OLI) are the most common and used data source; and 49% of articles report their utilization (Metternicht et al., 2010). Time series of LANDSAT images for 2000-2021 were processed via Google Earth Engine (GEE) open-source data cube. LANDSAT is the most used database and is the largest component of the GEE data portal. A harmonization of LANDSAT 5, LANDSAT 7, and LANDSAT 8 satellite data was implemented and a series of fragments with less than 30% cloud cover were selected for processing. The harmonization process was carried out by applying surface reflectance sensor transformation functions (ETM+ to OLI and OLI to ETM +) and coefficients proposed by Roy. This enables the transformation of ETM+ surface reflectance to OLI surface reflectance or vice versa (Roy et al., 2016). In total, 1087 fragments were processed via calculating, during which we encountered a problem related to some distorted fragments. Since June 2003, the sensor has acquired and delivered data with gaps caused by the Scan Line Corrector (SLC) failure. However, this fact does not force ejecting the distorted fragments, since it may result in missing valuable data. Various vegetation indices are used to determine the viability of agricultural sites, especially pastures and grasslands. The most common and used index is the Normalized Difference Vegetation Index (NDVI): a standardized way to measure the health of vegetation (biomass) NDVI imagery allows farmers to analyze vegetation conditions for all seasons from NDVI maps, curves, and values, as well as predict productivity and potential yield. NDVI shows the vigor level of the crop and it is calculated as the ratio between the difference and the sum of the refracted radiations in the near-infrared and the red, that is as (Roy et al., 2016) ,

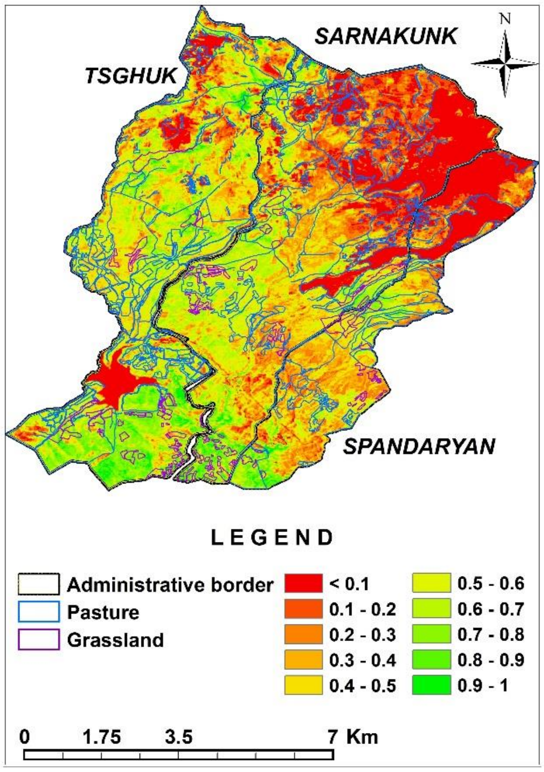
$$NDVI = \frac{NIR-RED}{NIR+RED} \qquad (1)$$

where NIR = Near-infrared

RED = Red

2.3 Image processing and testing

Time series of NDVI values were calculated in the GEE platform using JavaScript scripting, for the April-October season of the 2000-2021 time period and a set of maps for 2000, 2005, 2010, 2015, and 2021 years (Figure 1, Figure 2) were produced via ArcGIS 10.6 which we will show the state of the biomass for each fifth year in the study period. The NDVI values were classified according to the scheme presented in Table 1. (“Agricolus,” n.d.)



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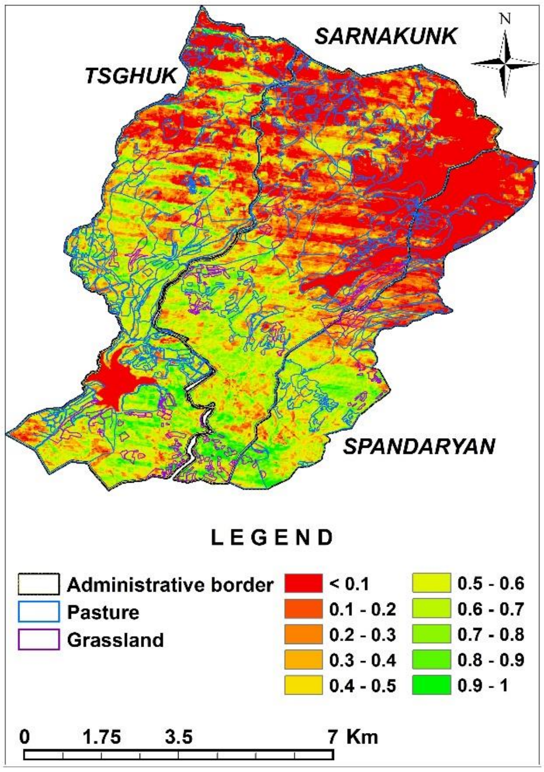

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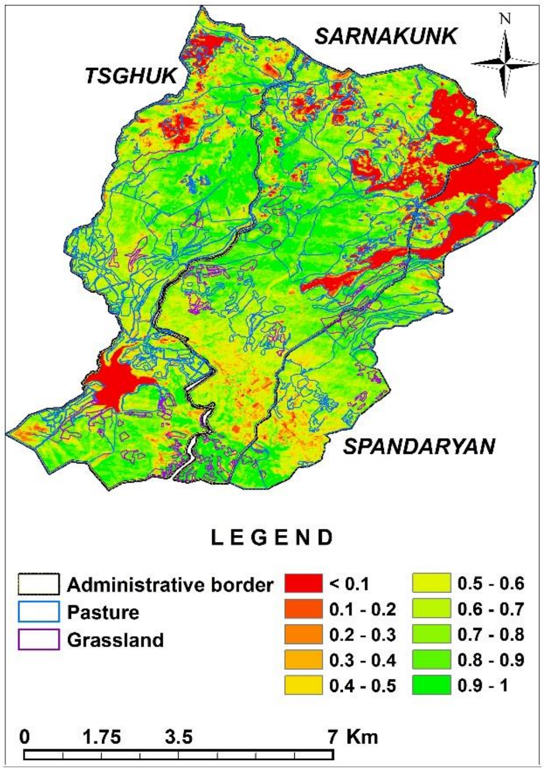

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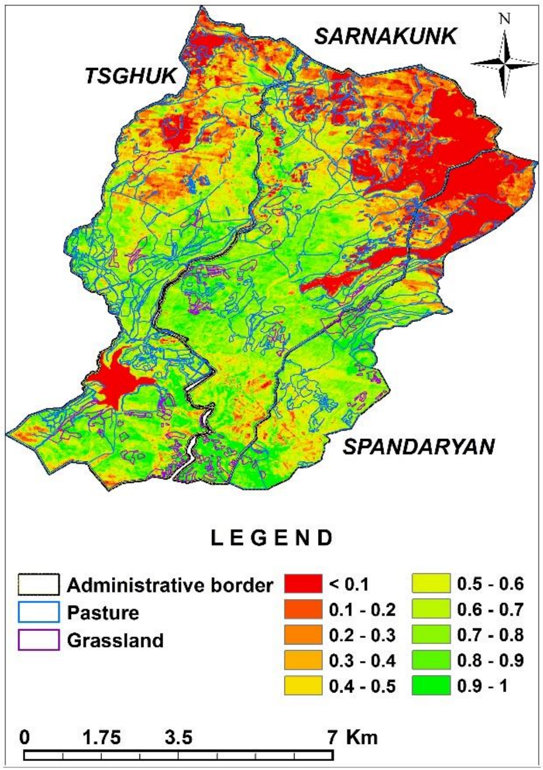

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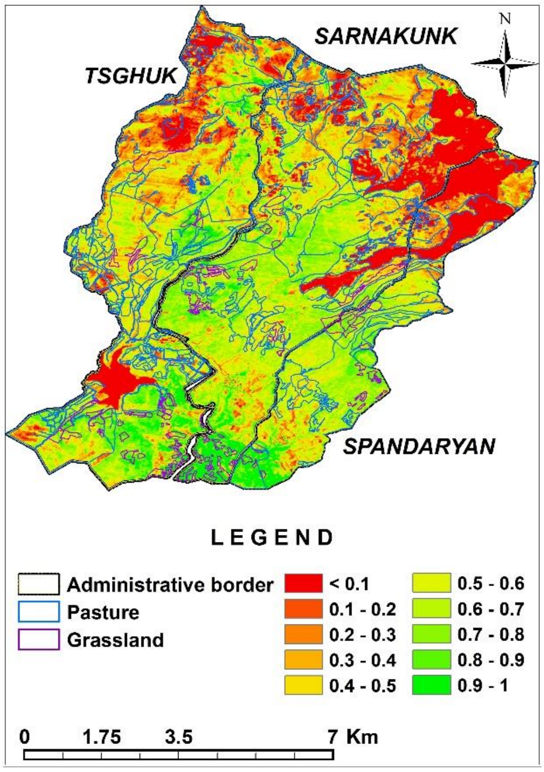
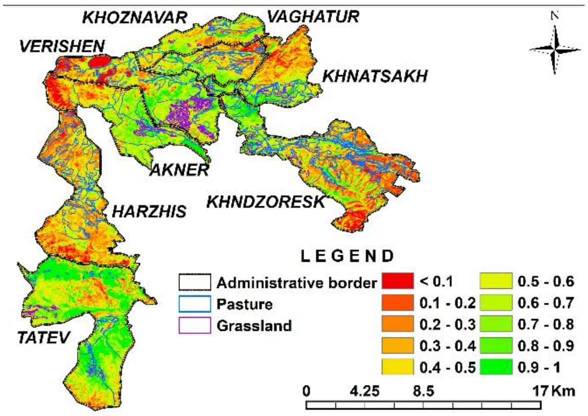


e)

Figure1. The NDVI values of the pastures and grassland of the rural communities (Tsghuk, Sarnakunk, Spandaryan) of Sisian region: a) 2000, b) 2005, c) 2010, d) 2015, e) 2021.



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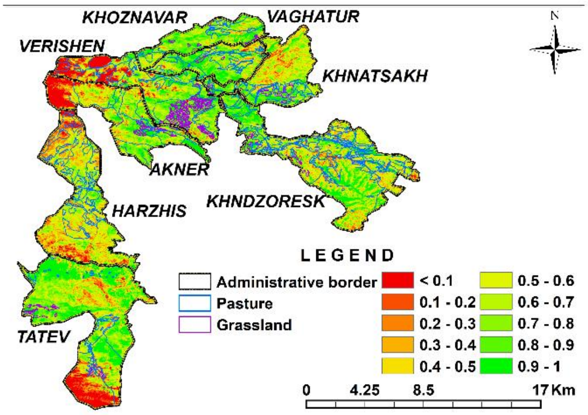

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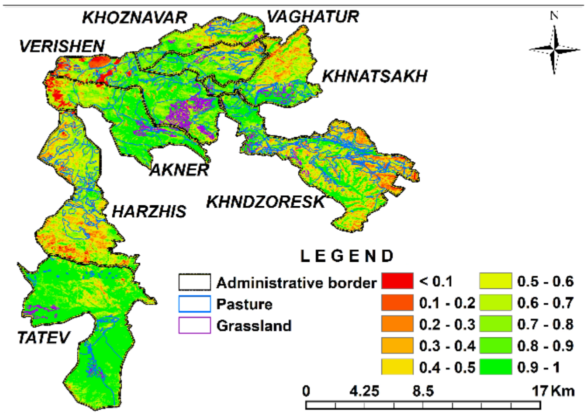

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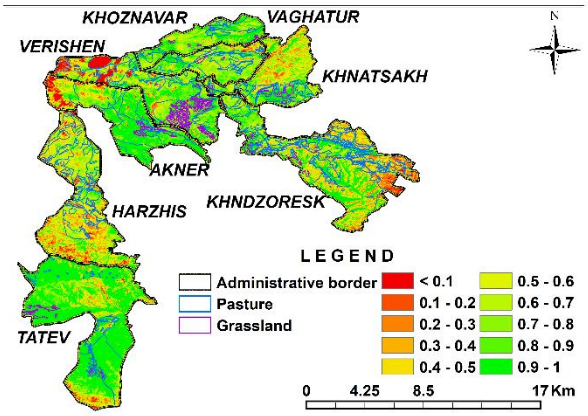

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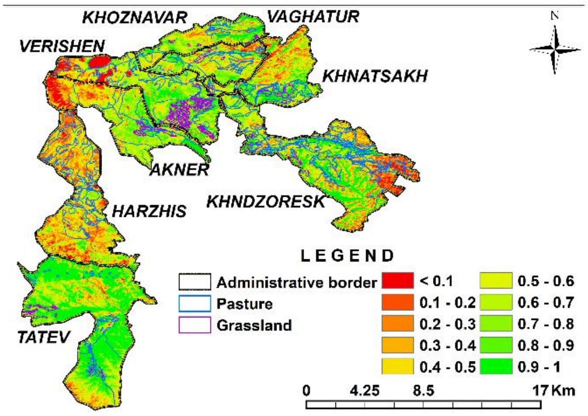

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Figure2. The NDVI values of the pastures and grassland of the rural communities (Tatev, Harzhis, Akner, Verishen, Vaghatur, Khnatsakh, Khoznavar, Khndzoresk) of Goris region: a) 2000, b) 2005, c) 2010, d) 2015, e) 2021.

The NDVI values were classified according to the scheme presented in Table 1. (“Agricolus,” n.d.)

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

Table 1. Classification of NDVI values of agricultural plots

Afterward, trend analysis was performed on the Jupiter Netbook platform via the Seasonal Mann-Kendall statistical test (Mavromatis and Stathis, 2011), using Python coding. The Mann-Kendall calibration method was chosen, which is widely used for the analysis of trends in climatic and hydrological time series (Shadmani et al., 2012). There are two advantages to using this test, it is a non-parametric test and does not require a normal distribution of the data, and the test has low sensitivity to sharp time discontinuities due to inhomogeneous time series (Shadmani et al., 2012). Moreover, it allows us to take seasonality into account as well. Any data reported as non-detects are included by assigning them a total value that is less than the smallest measured value in the data set (Mavromatis and Stathis, 2011). Under this test, the null hypothesis H_0 assumes that there is no trend and this is tested against the alternative hypothesis H, which assumes that there is a trend. A null hypothesis was proposed assuming that there is no trend between variables. T, H, P, α (0.05), and Z are descriptive parameters, which show the state of, alternative trend, value of the significance, significance level, and standardized statistic test accordingly. The positive Z indicates an increasing trend in the time series, while the negative Z is a decreasing trend (Buhairi, 2010).

3. RESULTS

The research reveals crucial insights into the state of biomass in the grasslands and pastures of the Sisian and Goris regions over 22 years, from 2000 to 2021. By utilizing the NDVI values as a key indicator, the study sheds light on the overall health and trends of vegetation in these areas with high agricultural importance. Figure 1 shows that according to the NDVI values, the state of the biomass in grasslands and pastures of the rural communities of the Sisian region in 2010 and 2015 is much better than in 2000, 2005, and 2021. Figure 2 demonstrates that in the Goris region, the situation is a little bit different. The state of the biomass is better in 2005, 2010, and 2015 than in 2000 and 2021. While, the time series analysis through the Seasonal Mann-Kendal test shows that no trend is observed neither in grasslands nor in pastures of the Sisian region (Tsghuk, Sarnakunk, and Spandaryan). So, the null hypothesis is confirmed, due to P and Z values (Table 2): P > α, and |Z| > 1,96 (critical value of Z, if α=0,05) (Shadmani et al., 2012).

		Trend	***H***	***P***	***Z***	***α***
Tsghuk	*Pasture*	No	False	0.238	1.179	0.05
	Grassland	No	False	0.392	0.854	0.05
Sarnakunk	*Pasture*	No	False	0.206	1.262	0.05
	Grassland	No	False	0.193	1.300	0.05
Spandaryan	*Pasture*	No	False	0.131	1.507	0.05
	Grassland	No	False	0.057	1.897	0.05

Table2. The descriptives of the Seasonal Mann-Kendall test of the rural communities (Tsghuk, Sarnakunk, Spandaryan) of the Sisian region.

According to the Seasonal Mann-Kendal statistical test in the Goris region, no trend is observed for both pastures and grasslands of Vaghatur and Khoznavar rural communities and for grasslands of Khnatsakh rural community where P > α, and |Z| > 1,96. However, a positive trend is observed for both pastures and grasslands of Tatev, Harzhis, Akner, Verishen, and Khndzoresk communities, and for the grasslands of Khnatsakh village according to the P and Z values:P < α and |Z| > 1,96 (Table 3).

		Trend	***H***	***P***	***Z***	***α***
Tatev	*Pasture*	Yes	True	0.002	3.060	0.05
	Grassland	Yes	True	0.024	2.244	0.05
Harzhis	*Grassland*	Yes	True	0.014	2.451	0.05
Akner	*Pasture*	Yes	True	0.0002	3.635	0.05
	Grassland	Yes	True	0.006	2.739	0.05
Verishen	*Pasture*	Yes	True	0.010	2.549	0.05
	Grassland	Yes	True	0.037	2.082	0.05
Vaghatur	*Pasture*	*No*	*False*	0.138	1.483	0.05
	Grassland	*No*	*False*	0.130	1.512	0.05
Khnatsakh	*Pasture*	Yes	True	0.002	3.035	0.05
	Grassland	*No*	*False*	0.154	1.422	0.05
Khoznavar	*Pasture*	*No*	*False*	0.080	1.745	0.05
	Grassland	*No*	*False*	0.072	1.794	0.05
Khndzoresk	*Pasture*	Yes	True	0.001	3.210	0.05
	Grassland	Yes	True	0.002	2.968	0.05

Table3. The descriptives of the Seasonal Mann-Kendall test of the rural communities (Tatev, Harzhis, Akner, Verishen, Vaghatur, Khnatsakh, Khoznavar, Khndzoresk) of the Goris region.

It is significant that, for the Sisian and Goris regions, the calculated Z-values were found to be positive in all cases, indicating a consistently favorable state of vegetation over the entire 22-year time series. This uniformity in positive values across both regions suggests that, on the whole, the vegetation has been thriving and resilient over the long period, despite any localized fluctuations in biomass health.

4. CONCLUSIONS

Seasonal Mann-Kendall statistical testing enables to validatation of the results of the time series analysis to identify the trend and trend behavior of spatio-temporal changes. No trend of NDVI values in the time series 2000-2021 was observed in pastures and grasslands of Tsguk, Sarnakunk, and Spandaryan rural communities of the Sisian region, and hence no change in biomass condition was observed. While in the pastures of the Khnatsakh community of Goris region and in pastures of Vaghatur and Khoznavar no change in the biomass condition was observed, while in the grasslands of Khnatsakh village and in both grasslands and pastures of Akner, Khndzoresk, Verishen, Tatev, Harzhis rural communities an improvement in the biomass condition was noted. So, no degradation of the biomass condition was observed in the studied clusters of the rural communities in the Goris and Sisian regions, but improvement was observed only for those of the Goris region. By recognizing the positive trends and resilient state of vegetation, policymakers and local communities can work together to develop strategies that protect and enhance the vital grasslands and pastures in Sisian and Goris, ensuring the preservation of these valuable ecosystems for future generations. The identification of specific communities with positive trends in vegetation health can serve as a basis for implementing targeted interventions to promote further improvements.

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