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THE EFFECT OF THE ALTITUDE GRADIENT ON THE VEGETATION OF THE GRASSLANDS IN THE POIANA RUSCĂ MOUNTAINS, BASED ON NDVI

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Abstract

The relief is the main factor that determines the "vertical" arrangement of the vegetation. Starting from this hypothesis, the aim of the study is to quantify the influence of the altitudinal gradient on the vegetation cover of the grasslands and to test the condition of maintaining this influence over time. The Normalized Difference Vegetation Index (NDVI) was used, applied to Sentinel 2 images from March, May, July, August, October. It was established that, in grasslands, the average values of NDVI are minimum in spring, beginning of the vegetation season (0.3743), increase in May (0.6775) and reach the maximum in July (0.8233 - high degree of coverage). In autumn, the vegetation cover decreases (NDVI = 0.6258). On the altitudinal gradient, in spring, vegetation cover decreases with increasing altitude (r = -0.85), in summer, it is "uniformly" distributed, and in autumn, it increases simultaneously with altitude (r = 0.5831), against the background of maintaining a temperature-precipitation ratio optimal on the upper floors. The use of NDVI in the analysis of grassland provides a global picture and the possibility of expanding the analysis in different research directions.

***Key words**: altitudinal variation, grasslands, NDVI, vegetation.*

INTRODUCTION

It is well known that relief, through altitude, slope, or the exposure of slopes, is the main factor determining the "vertical" zoning of other environmental factors, which influences the typology and distribution of vegetation cover, including grassland entities (Bennie, 2003; Lieffers & Larkin-Lieffers, 2011; Lieffering et al., 2019; Wang et al., 2023). Altitude, as an abiotic factor, is reflected in the distribution, composition of plant species, and the structure of grassland habitats, both directly and indirectly, by modifying climate and soil conditions (Austrheim, 2002; Mayor et al., 2017; Bagousse-Pinguet et al., 2019).

In recent years, numerous remote sensing applications and Geographic Information Systems (GIS) have been developed for analyzing grasslands in correlation with relief factors or other environmental factors, surpassing the limitations of traditional methods and offering the possibility of complex analyses with multidisciplinary significance (Pyke et al., 2002; Li et al., 2014; Zlinszky et al., 2015; Hatfield et al., 2019; Soubry et al., 2021; Bobric et al., 2023). Understanding the distribution and evolution of vegetation, as well as monitoring grassland areas, is an important issue, especially for local communities dependent on these natural resources (Thomas et al., 2013; Caluseru et al., 2015; Mokarram et al., 2015; Copăcean et al., 2020; Simon et al., 2020).

An extremely useful tool in investigating grasslands in relation to environmental factors, with multiple applications, is the Normalized Difference Vegetation Index (NDVI). This index has been widely used for assessing the vegetation growth status of grasslands (Fensholt et al., 2009; Boori et al., 2020), temporal and spatial changes in vegetation cover (Gandhi et al., 2015), estimating biomass quantity, and the health status of grasslands (Bento et al., 2020; Soubry et al., 2021; Wang et al., 2022).

The hypothesis for this study, supported by numerous specialized studies in different areas, is that vegetation distribution varies according to altitude (Piao et al., 2011; Zhang et al., 2021; Hua et al., 2022). Furthermore, the idea of seasonal variation in grasslands, located in extensive areas under variable environmental conditions, has sparked interest. Based on these considerations, the question arose: *"What is the behavior of vegetation at different altitudes at distinct moments of the growing season?"* From this point, a new challenge emerged: whether the NDVI index could be a theoretically and practically applicable solution under the conditions of the area of interest.

In this regard, the aim of the study was, on one hand, to quantify the influence of the altitudinal gradient on vegetation cover in grasslands, and on the other hand, to test the condition of maintaining this influence over time during the growing season.

MATERIALS AND METHODS

Study area

The research was conducted in the Poiana Ruscă Mountains, located in southwestern Romania, within the administrative territories of three counties: Hunedoara, Caraş-Severin, and Timiş (Figure 1).

The study area is intersected by the 45°N parallel and the 22°E meridian. It has the shape of a quadrilateral with an area of 167,084 hectares. Along the N-S direction, the length of the area of interest is approximately 46 km and along the W-E direction, it is about 54 km.

From a geological perspective, the Poiana Ruscă Mountains are predominantly composed of crystalline schists, limestones, and crystalline dolomites (Rusu, 2007). Altitudinally, they range between 188 to 1374 meters, with the maximum altitude reached at Padeş Peak. The average elevation of the terrain is 706 meters.

The Poiana Ruscă Mountains belong to the transitional temperate continental climate sector. The multiannual average temperature varies between 9-11ºC in the low, marginal areas and between 2-8ºC in the mountainous area. The average annual amount of precipitation, due to oceanic influences, increases with altitude, from values of approximately 700 mm, in the marginal areas, to over 1000 mm, in the mountainous areas.

The eastern half of the Poiana Ruscă Mountains belongs to the Mureş watershed (the main rivers being Cerna and Strei), and the western part to the Bega river watershed. In the south, the Bistra river basin is individualized.

In terms of land use, the Poiana Ruscă Mountains are covered by forests to over 75% of their area, particularly in the western half (Rusu, 2007).

Human settlements were formed both on the interfluves (in the areas with narrow valleys and thermal inversions), and on the valleys, in the depression basins in the northwest.

Materials used in research

The regionalization carried out by Posea and Badea was considered for delimiting the Poiana Ruscă Mountains (1984).

For the conduct of the research, the following geospatial data were utilized:

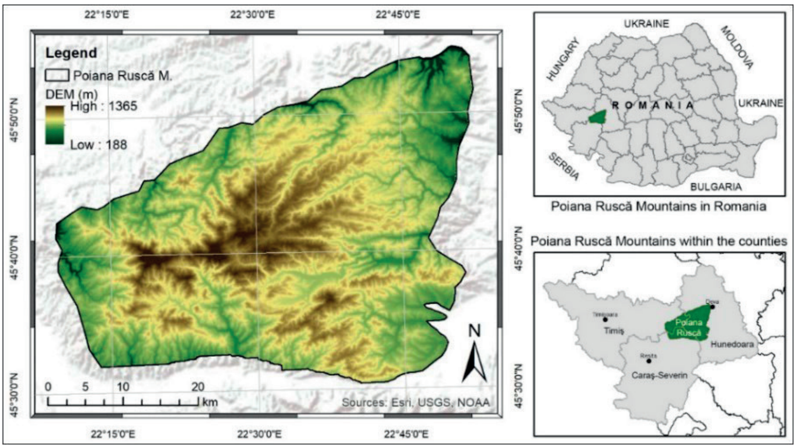

Figure 1 The location and the physical and geographical characteristics of the studied area (processing after EEA, 2016 2023; Geospatial, 2023; Posea & Badea, 1984)

- Sentinel 2A satellite imagery - for obtaining NDVI maps, downloaded from the Copernicus Open Access Hub platform;
- The Digital Elevation Model (DEM), in raster format, with a spatial resolution of 25 m, hybrid product based on SRTM and ASTER GDEM data, available for free on the platform of the European Environment Agency - for extracting altimetric information (EEA, 2016);
- Corine Land Cover (CLC) database, 2018 edition - for identifying grassland areas.

The geospatial datasets were processed using the SNAP and ArcGIS 10.4 software.

The methodology employed

The workflow involved several stages, as depicted in Figure 2:

1. ***The satellite imagery download***. In the case of this study, for the application and testing of the work algorithm, the "experimental year" 2019 was chosen, in which five temporal moments of the vegetation season were selected, marked T_0....T_4, respectively 28.03, 11.05, 01.07, 10.08 and 09.10. We opted for the analysis over different periods, considering the fact that the vegetation has different "behavior" and characteristics, depending on the vegetation phases. For each of these moments in time, two Sentinel 2A MSI satellite scenes were downloaded, with the atmospheric corrections and georeferenced in the UTM (Universal Transverse Mercator) system, from the areas with the code 34TER and 34TFR (taking into account the fact that the area of interest is partially overlaps both scenes).
2. ***Processing satellite scenes in SNAP*** involved mosaic creation, band conversion to the same spatial resolution (20 m), approximate extraction of the area of interest, and generation of NDVI maps for the five temporal moments considered.
3. ***The processing of the DEM*** involved extracting the area of interest and classifying it into 11 altitude classes with an altitude range of 100 meters (between 188 and 1374 m);
4. ***The identification of grassland areas*** utilized the CLC 2018 database, from which the secondary grasslands class (code 231) and natural grasslands class (code 321) were extracted. The spatial entities were validated based on cadastral maps, orthophotoplanes, and GPS points collected in the field (Table 1).
5. ***The extraction of NDVI values for grassland areas*** involved retrieving both spatial entities and numerical values required for statistical data processing from the NDVI maps.
6. ***Spatial analysis, for grasslands***, involved correlating NDVI with altitude to identify the trend of NDVI values as altitude values change.

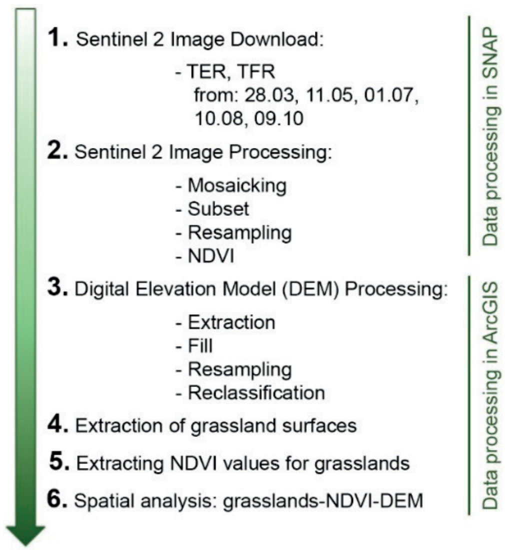

Figure 2. Workflow

Table 1. The accuracy assessment of geospatial data through ground control points

	Grasslands	Others	Total	Accuracy (%)	Prediction (%)
Grasslands	31	4	35	88.57	86.11
Others	5	0	5	100.00	13.89
Total	36	4	40		
	Grasslands	Others	Total	Commision	Producers accuracy
Grasslands	31	0	31	0.00	1.00
Others	4	5	9	0.44	0.56
Total	35	5	40		
Commision	0.11	0.00			
Producers accuracy	0.89	1.00			
Overall accuracy	0.90	0.90			
K	0.56				
p(r)	0.78				

For the analysis of climatic conditions in the area of interest, climatic data (Climatic Databases, 2023) were retrieved, including monthly average temperatures and monthly precipitation amounts for the year of 2019, from 26 nearby meteorological stations, located at different altitudes.

RESULTS AND DISCUSSIONS

According to the Corine Land Cover (CLC) database, 2018 edition, grassland areas have been identified covering 21,890 hectares, which represents 14.74% of the total surface of the study area (Figure 3).

The grasslands of the Poiana Ruscă Mountains are extremely varied from the point of view of the floristic composition, respectively they are characterized by a great biodiversity. Thus Maruşca et al. (2020) in the representative grasslands of the Poiana Ruscă Mountains identify several phytosociological alliances: Al. *Festucion rupicolae* (As. *Agrostideto capillaris - Festucetum rupicolae*, As. *Botriochloetum ischaemi,* As. *Brometum fibrosi*); Al. *Cynosurion* (As. *Festuco rubrae - Agrostietum capillaris*); Al. *Violo declinatae - Nardion* (As. *Violo declinatae - Nardetum*); Al. *Trifolion medii* (As. *Clinopodio - Pteridietum*); Al. *Agropyro - Rumicion* (As. *Trifolio repenti - Lolietum perennis*); Al. *Molinion coerulae* (As. *Peucedano - Molinietum*), respectively Al. *Potentillion anserinae* (As. *Junco inflexi - Menthetum longifoliae*). The variety of species in the meadows also have different periods of initiation into vegetation, respectively growth, fruiting and senescence during the vegetation period, an aspect that influences the values of the NDVI index.

In the case of the vegetation cover of the grasslands, the analysis based on the NDVI values (Figure 3), highlighted significant variations, during a sequence of the vegetation season, an aspect also noticed by other studies (Copacean et al., 2023).

The expeditious analysis of the NDVI maps (Figure 3) shows that in addition to the "horizontal" variation, from one sequence of the vegetation season to another, there is also a "vertical" variation, under the influence of altitude.

The analysis of environmental factors directly influencing the spatial distribution of grassland vegetation

The analysis of grasslands in relation to the relief shows their uneven distribution in the vertical plane, indicating different conditions for the formation and evolution of vegetation (Figure 4). Among the grasslands in the study area, 78% are located at altitudes between 400-800 m, with an average altitude of 718 m. Of the total grassland areas, 61% are situated on terrain with slopes between 5-15º (Figure 4), suggesting variability in the vegetation cover along the altitudinal gradient, considering that the relief is the main determining factor of vegetation spatial distribution. The average slope of the grassland areas is 10.3º

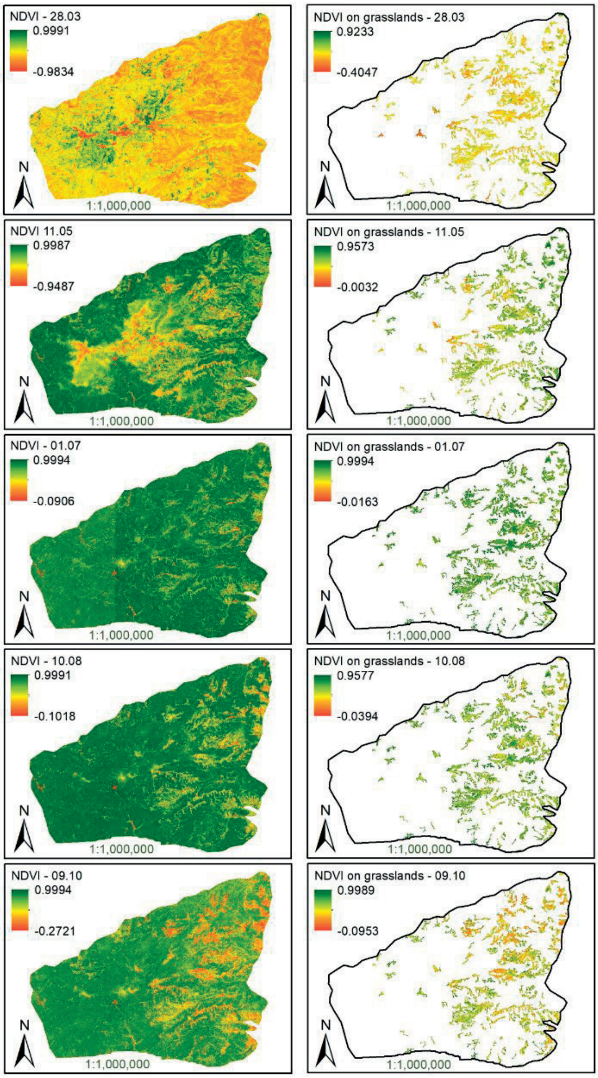

Figure 3 The distribution of the NDVI values in the study area for T_0-T_4
(processing after: Geospatial, 2023; Copernicus Open Hub, 2022)

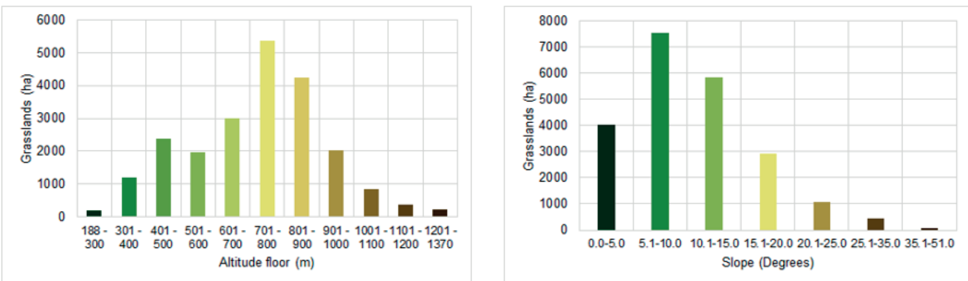

Figure 4 The distribution of grassland areas by altitude zones (left) and slope classes (right)

Furthermore, relief directly and indirectly influences the "behavior" of climatic factors, which in turn determine the characteristics and distribution of vegetation (Gonga et al., 2008). In the case of the study area, based on climatic data recorded at 26 nearby meteorological stations, it was found that air temperature decreases with increasing altitude (r = -0.9711), following a vertical thermal gradient of 0.53ºC/100 m altitude. Regarding precipitation, a weak to moderate correlation with altitude was determined (r = 0.5332), with values increasing vertically but being influenced by local conditions (Figure 5).

The analysis of the relief and climatic factors, in correlation with grasslands, which are altitude-dependent variables, supports the hypothesis of variability in the vegetation cover degree along the altitudinal gradient.

The analysis of the vegetation cover variation in grasslands during the period from March to October, by altitude zones

To highlight the variation in grassland vegetation cover degree vertically, NDVI values in grasslands located at different altitudes were analyzed at different time points.

In T_0, the first considered stage (March), the grassland cover degree was low since plants had not started growing yet due to restrictive climatic conditions. At this stage, the influence of altitude is evident (Table 2, Figure 6), with a strongly negative correlation established with NDVI values (r = -0.8406, ts = -0.0100). This is explained by the fact that most grassland plants start growing at temperatures above 10ºC, for at least 7 consecutive days, a condition not met at higher altitudes (Figure 5).

The NDVI calculated for T_0 has low values with a similar trend across all altitude thresholds except for grasslands located between 1200-1370 meters (Figure 6), where the lowest values are observed (0.2680). The fact that NDVI is maintained at low values, on all altitudinal levels (does not show significant variations) suggests that the plants in the grasslands have not entered vegetation, with few exceptions.

At T_1, compared to T_0, as temperatures rise and moderate precipitation occurs (700-1000 mm/year), the grassland vegetation cover degree increases. There is a variation in vegetation growth with altitude, with a strong negative linear correlation with NDVI values (r = -0.9600, ts = -0.0300), indicating a reduction in cover degree towards the high mountain zone, where vegetation grows later. Although higher values are observed compared to T_0, restrictive climatic conditions for grassland plant growth and development still persist (Figure 5).

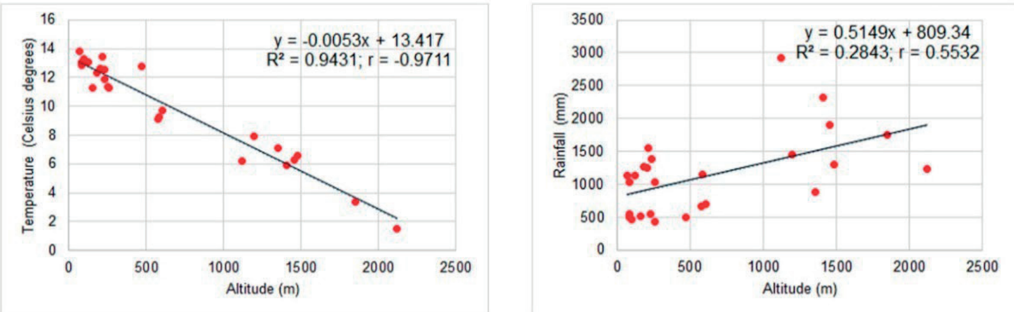

Figure 5. Correlation between temperature and altitude (left) and precipitation and altitude (right)

Table 2. Values of correlation coefficients in T_0-T_4 (March - October interval)

Specification	T_0	T_1	T_2	T_3	T_4
The regression equation	y = -0.0001x + 0.456	y = -0.0003x + 0.8878	y = -0.0001x + 0.8255	y = 0.0025x + 0.7598	y = 0.0063x + 0.5763
R^2	0.7067	0.9216	0.0044	0.2807	0.3346
r	-0.8406	-0.9600	-0.0665	0.5298	0.5784
Theil Sen (ts)	-0.0100	-0.0300	0.0000	0.0000	0.0100

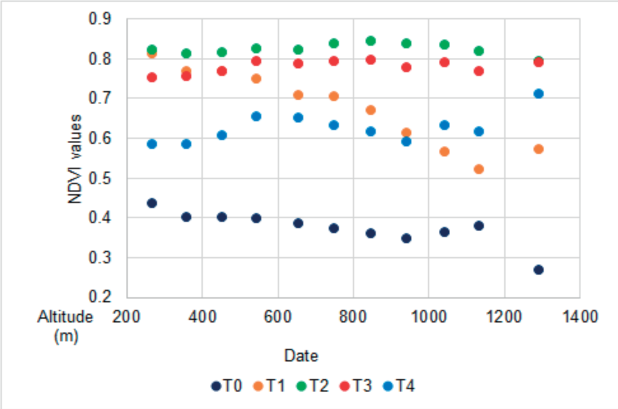

Figure 6 Correlation between NDVI (average) and altitude in T_0-T_4 (March - October interval)

In T_2, the NDVI values show the maximum degree of vegetation cover (Figure 6), with an average value of 0.8233. A dependency relationship between NDVI and altitude was not established (r = -0.0665, ts = 0.0000), indicating vegetation uniformity along the altitudinal gradient. At this moment, both in the lower and upper altitudes, plants meet optimal development conditions (above 17ºC) and cover the ground to a very high extent. For the specific conditions in the Poiana Ruscă Mountains, T_2 is the moment when a "growth peak" is observed, a situation also noted in other studies for different environmental conditions (Hu et al., 2009; Bickford et al., 2011; Spasojevic et al., 2013).

Translated into practice, in the month of July the largest amount of vegetable mass is recorded for the animals that use the grassland.

In Romania, similar to the Poiana Ruscă Mountains, the month of August (T_3) generally has similar thermal conditions to July (T_2), but with reduced precipitation amounts, which translates into reduced physiological activity of plants in the pastoral landscape. Growth stagnates, and seed formation occurs, leading to reduced chlorophyll activity and a decrease in NDVI. Altitudinal trends and vegetation cover uniformity remain similar to T_2 but with lower NDVI values (Figure 6), except for the upper elevation range (1200 - 1370 m), which benefits from greater amounts of precipitation (over 1000 mm/year).

Both in T_2 and T_3, the NDVI variation with altitude follows a similar pattern: values increase from the lower part up to about 1000 m, likely due to increased precipitation.

In recent years, global climate change (Allamano et al., 2009; Rogora et al., 2018; Şmuleac et al., 2020; Losapio et al., 2021; Sărăţeanu et al., 2023), has influenced the vegetation period.

In Romania, this period extends until the end of September or early October, which is reflected in the NDVI values for the study area. The NDVI-altitude correlation in T_4, weak to moderately positive (r = 0.5784, ts = 0.0100), indicates a high vegetation cover degree in the upper elevations, where optimal conditions for grassland plants persist even at the beginning of October. Compared to T_3, the average NDVI values decrease from 0.7787 to 0.6258.

The variation in NDVI values with altitude is explained by topoclimatic conditions: values are influenced by local conditions. NDVI values may differ where grasslands are bordered by large forested areas, creating locally humid microclimates and/or if the grasslands are located on north-facing slopes with reduced insolation and excess water balance (Barnard et al, 2017; Lieffering et al., 2019). In both situations, a prolongation of the vegetation season can occur.

The management practices of grasslands can also influence NDVI values: grazed grasslands typically exhibit greener vegetation compared to hayfields at harvest time, where plants are in a different phenophase and are senescing, reflecting electromagnetic radiation differently.

CONCLUSIONS

The relief, characterized by altitude, slope, or aspect, along with climate factors such as temperature and precipitation, are the main drivers of the vertical "zoning" of grassland vegetation and its behavior throughout a growing season.

In the case of grasslands, NDVI variation during the growing season indicates fluctuations in vegetation cover: minimum average values in spring (0.3743), as plants begin their growth phase, increasing in May (0.6775), and reaching a peak in July (0.8233). During this time, the vegetation cover of the grasslands is dense and covers the ground almost entirely. By August, some species from the upper vegetation layer and those left uneaten by animals have dried, leading to a slight change in NDVI values (0.7787). In autumn, the vegetation cover decreases (NDVI = 0.6258).

Regarding the altitude, the extent of vegetation coverage in grasslands fluctuates both over different time periods and vertically, at various altitudes. NDVI values suggest that in T_0, regardless of altitude, vegetation cover is low, indicating unsuitability for grazing. In May (T_1), NDVI values show an increasing trend from lower to higher altitudes, indicating the possibility of grazing. Both T_2 and T_3 show extensive vegetation cover across all altitude ranges, with minor exceptions. T_4 also exhibits slight variations in altitude and marks the end of the summer season.

The correlation between NDVI and altitude indicated an uneven distribution of vegetation cover across different altitudes during the spring season, diminishing as altitude increased. Values become more uniform during the summer when, even at higher altitudes, plants find optimal conditions for development. In autumn, NDVI reveals a distribution of vegetation in altitude with a higher coverage degree in the upper elevations, under the conditions of the year 2019.

In a multidisciplinary perspective, NDVI can be a valuable tool not only in agricultural practice but also in ecology and natural sciences. Assessing grassland vegetation cover is crucial for marking the beginning of grazing and the duration of the grazing season, determining the degree of degradation, or maintaining long-term stability of the grassland ecosystem in the context of ongoing climate change.

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