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The use of spectral techniques to monitor the vegetation status in a protected area in the Iasi county

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Abstract: Remote sensing technology offers the possibility to monitor biophysical attributes and changes in plant biomass and productivity during the growing season, which can enable sustainable management. Recent advances in satellite remote sensing technology have produced innovative sensors for monitoring the Earth's surface, with increasing spatial and temporal resolution of available satellite images, such as those provided by the Sentinel-2, creating new opportunities for environmental monitoring and the generation of accurate datasets. This study aimed to assess vegetation condition during the spring, summer and autumn seasons in a protected area near Iasi, ROSCI0058, using biophysical indices derived from Sentinel-2 satellite imagery. The study area was chosen due to the existence of signals indicating the possibility of changes in the type and health status of vegetation within the site of Community importance. The analysis was based on a series of vegetation-specific spectral indices such as: normalized differential vegetation index (NDVI), leaf area index (LAI), canopy chlorophyll content (CCC), canopy water content (CWC), fraction of photosynthetically active absorbed radiation (FAPAR) and fraction of canopy cover (FCOVER), derived from Sentinel-2 high-resolution images. The time series of satellite images used covers the phenophase periods specific to the spontaneous flora in the period 2020-2022. With SNAP software the Sentinel-2 images were pre-processed to convert the reflectance of the ToA images to BoA, vegetation indices were calculated, after which final distribution maps were created with ArcGIS. The results indicate that the highest values for NDVI, LAI, FAPAR, FCOVER, CAB and CW did not follow a pattern, they occurred at different times of the year, as follows: in the spring season, the highest value was on April 10, 2020; in the summer season, highlighting the values of July 9, 2021 while for the fall, the year 2022 recorded the highest values on September 7, the results being directly proportional to the variation of climatic parameters. The analysis also considered the type of land use, with non-irrigated arable land having the highest values for various indices. The results highlight the potential of Sentinel-2 images for these types of studies, as they can be used to observe and assess the health of the vegetation cover.

1. Introduction

Remote sensing can be a valuable tool in monitoring protected areas, allowing for the collection of important information about the condition and health of ecosystems and wildlife populations. Protected areas refer to any area of land, water, or ice that is protected by law or other effective means from human activity and development (Nicoară et al., 2010; Mărgărint, 2010). These areas are designed to conserve the natural environment and ensure the long-term preservation of biodiversity, ecosystem services, cultural heritage, and other values. Protected areas may include national parks, wildlife reserves, biological reserves, natural monuments, forest reserves, marine protected areas, and other types of protected areas (Ardeleanu et al., 2021). They are often managed by government agencies or local communities, and restrictions on activities within protected areas may vary depending on the specific objectives of the conservation efforts (Yeqiao et al., 2020).

Remote sensing is an effective tool for monitoring vegetation and biophysical indices in protected areas at different spatial and temporal scales. Satellite imagery can be used to monitor large areas, providing information on vegetation cover, biomass, and productivity (Djmai et al., 2019). Vegetation indices are indicators of plant health, and biophysical indices relate to the physical characteristics of the ecosystem such as temperature, humidity, and water availability. By monitoring these indices, protected area managers can assess the health of the ecosystem and detect changes over time (Yeqiao et al., 2020). By using this technology, protected area managers can better understand the health of the ecosystem, detect changes over time, and make informed management decisions to protect these critical areas.

In order to analyze the current trends in the use of spectral indices calculated by remote sensing in the monitoring and assessment of the health status of a protected area, a computational solution was chosen, using VOSviewer software. A database of articles published in Web of Science (WOS) between 2014 and 2022 was created using as filters the following keywords: Remote Sensing, Sentinel 2, Biophysical indices, Land-use, Protected Areas, totaling 240 articles. The co-occurrence and linkages between items were analyzed on the bibliometric network visualization map created, being symbolized by those lines connecting the different items, the strength of the linkage visualized indicating the number of publications and the nature of the connection between items. This resulted in 69 items classified by the VOSviewer algorithm into five clusters, each of which constitutes a grouping of research activities completed by subsequent publication as follows: (i) red cluster 21 items, (ii) green cluster -19 items, (iii) blue cluster 14 items, (iv) yellow cluster- 10 items and (v) purple cluster -5 items, each cluster indicating the relationships between one term to another. The size of the letters is determined by the frequency of occurrence of the term. A simplified interpretation and labelling are suggested for each cluster in Table 1.

Figure 1. VOSviewer output of keyword co-occurrences

Table 1. Interpretation of the co-occurrence clusters from Figure 1.

Cluster	Color	Label	Key words
1	Red	Remote sensing	Landscape, GIS, deforestation
2	Green	Management	Indicators, forest, ecosystem services
3	Blue	Conservation	Climate change, dynamics, NDVI
4	Yellow	Vegetation	Biodiversity, classification, imagery
5	Purple	Protected areas	Normalized vegetation index

The role of vegetation in maintaining ecological security is significant, as it is one of the most crucial land resources. The growth conditions and coverage of vegetation provide essential integrated indicators of environmental health. With climate change's cumulative impact worldwide over the past few decades, the importance of vegetation cover and its dynamics has increased significantly (Ciutea et al., 2020).

2. Materials and methods

2.1 Study area

The ROSCI0058 site is located in the NE Region of Romania, in the Jijia-Bahlui Plain, at a distance of 10 km from the limit of the extended urban area of the municipality of Iasi and 21 km from the center of the municipality (Figure 2).

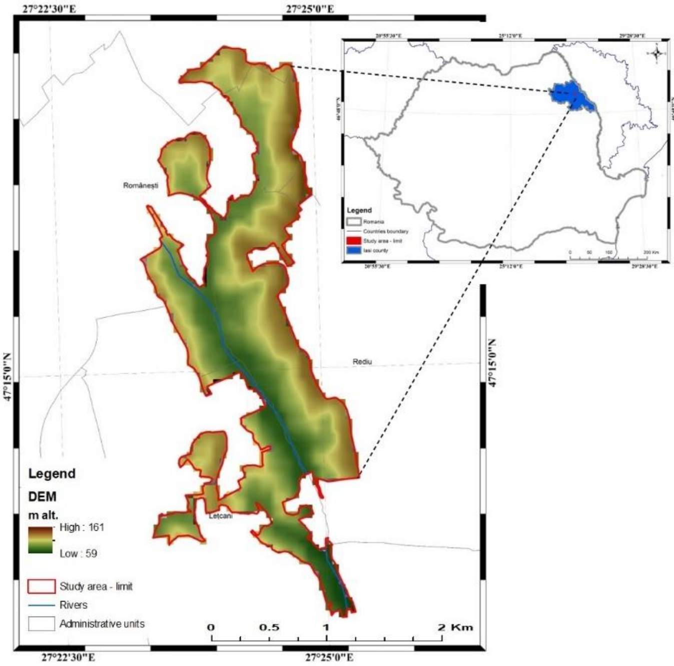


Figure 2. Study area localization

The ecosystems present in the ROSCI0058 site represent the cenotic framework that supports the populations of rare and important species at the community level and the dynamic factor that influences the living conditions in the habitat, within more or less constant limits. Thus, the xeric grassland ecosystem is a grassland with a pronounced steppe character, with saline patches in the valleys, with a low degree of fragmentation mainly due to salinity in the valleys, has a characteristic structure, with typical species relatively well represented in the site. The xerophytic scrub of the northern silvosteppe is present only in punctiform form or as islands with areas ranging from 50 m² to 400 m², and is relatively well preserved at the site. The xeric scrub ecosystem in the northern silvosteppe is quite fragmented, showing a characteristic structure, with typical species present and relatively well represented in the site (Ursu and Nicoară, 2013).

2.2 Materials and methods

For this study, was used Sentinel 2 MSI images for 2020-2022 period and Corine Land Cover data for 2018 year (https://land.copernicus.eu/). The Sentinel 2 images without cloud cover were downloaded for three seasons: spring, summer and autumn from Copernicus Open Access Hub (https://scihub.copernicus.eu/). Also, was used ERA5 data for monthly average temperature and precipitation parameters (https://cds.climate.copernicus.eu/). The ERA5 dataset is based on a state-of-the-art numerical weather prediction model, which is used to assimilate observations from a variety of sources, including satellites, ground-based measurements, and weather balloons. The resulting dataset covers the period from 1979 to the present day and is updated on a regular basis with new data. ERA5 data can be accessed through the ECMWF's Climate Data Store (CDS), which provides a range of tools for searching, downloading, and analyzing the data. The data is available in a variety of formats, including netCDF, GRIB, and CSV, and can be downloaded either as individual files or as part of a larger dataset (Muñoz, 2019).

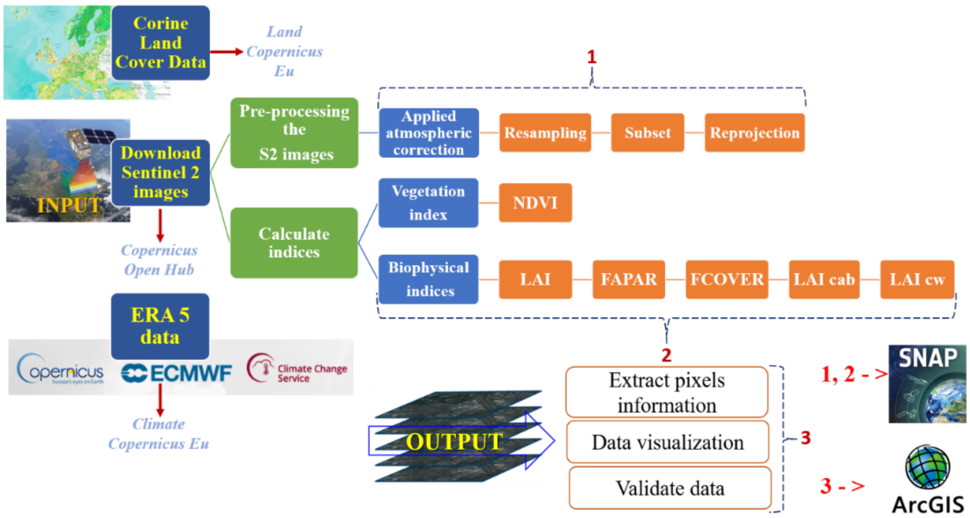


Figure 3. Methodological flow used in this study

2.2.1 Sentinel 2 images

The Copernicus SENTINEL-2 mission comprises a constellation of two polar-orbiting satellites placed in the same sun-synchronous orbit, phased at 180° to each other (https://sentinel.esa.int/). The aim of this mission is to monitor the variability in land surface conditions, and its wide swath width and high revisit time will support the monitoring of Earth's surface changes.

The data taken into analysis were selected taking into account data from different phenological phases to capture the vegetative phase, flowering and senescence of plants (from 05 April 2020 to 17 October 2022). After the downloading process all images were corrected atmospherically using Sen2Cor processor in SNAP program. In this way was converted from L1C - Top of the Atmosphere (TOA) into L2A - Bottom of the Atmosphere (BOA) images. The preprocessing steps was: resampling, subset and reprojection (Figure 3). The resampling step converts all thirteen spectral bands of different resolutions (60 m, 20 m and 10 m) into 10 m resolution images; being followed by the area of interest extraction step, at the end the Romanian characteristic projection (EPSG 31700: Stereo 70) is applied (Djmai et al., 2019).

Table 2 provides details of the main characteristics of the thirteen S2-MSI spectral bands used for estimating vegetation biophysical variables using the Sen2Cor processor. Bands B1, B9 and B10 are mostly dedicated to the atmosphere or clouds, the remaining ten bands can be used for vegetation characterization. Most of them have a spatial resolution of 20 m, except B2, B3, B4 and B8, which have one of 10 m (Hojas-Gascón, 2015).

After the preprocessing steps, several vegetation and biophysical indices was computed, such as: Normalized Difference Vegetation Index (NDVI), Leaf area index (LAI), Fraction of Absorbed Photosynthetically Active Radiation (FAPAR), Fraction of Green Vegetation Cover (FCOVER), Canopy Chlorophyll Content (CAB) and Canopy Water Content (CW). The Leaf Area Index (LAI) can be mathematically expressed as the ratio of the total photosynthetically active surface area of leaves and other elements of vegetation to the corresponding horizontal ground area. This fundamental vegetation parameter plays a key role in quantifying the exchange of energy and matter, such as radiation and gases, between the canopy and the surrounding atmosphere by determining the magnitude of their interface (Garrigues et al., 2008). The Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) is a parameter that represents the proportion of incoming photosynthetically active radiation that is absorbed by the vegetation canopy. This value is calculated using a radiative transfer model that accounts for the instantaneous conditions within the canopy, including its structure, optical properties of the vegetation elements, and illumination characteristics (Weiss et al., 2000).

Table 2. Sentinel-2 Multispectral Imagery (S2 - MSI) bands used by Sen2Cor processor

Sentinel 2 – MSI			
Band name	**ID**	**Bandwidth (nm)**	**Spatial Resolution (m)**
Coastal aerosols	B1	433-453	60
Blue	B2	458–523	10
Green	B3	543–578	10
Red	B4	650–680	10
Red-edge 1	B5	698–713	20
Red-edge 2	B6	733–748	20
Red-edge 3	B7	773–793	20
Near-Infrared	B8	785-899	10
Near-Infrared narrow	B8A	855-875	20
Water vapour	B9	935-955	60
Shortwave-Infrared / Cirrus	B10	1360-1390	60
Shortwave-Infrared (SWR1)	B11	1565–1655	20
Shortwave-Infrared (SWR1)	B12	2100-2280	20

The Fraction of Vegetation Cover (FVC) is defined as the proportion of the sky hemisphere that is obstructed by vegetation when viewed from directly above (nadir direction). Unlike FAPAR, which is sensitive to illumination geometry, FVC is solely determined by canopy structural properties, such as leaf area index, and does not rely on other variables. This characteristic makes FVC a promising candidate for replacing conventional vegetation indices in the monitoring of green vegetation, as it can be used to separate vegetation and soil in energy balance processes related to temperature and evapotranspiration. Chlorophyll content is a highly reliable indicator of stress factors, such as nitrogen deficiencies, and has a strong correlation with leaf nitrogen content, as reported by Xie et al. (2019). The spectral configuration of SENTINEL2 enables the estimation of a crucial variable, namely the water content of vegetation, which strongly absorbs radiation in the near and middle infrared regions. Given that water constitutes a significant portion of living plant mass (between 60% and 80%), this variable is of great importance for plant growth and development. The preferred measure of water content in vegetation, with regards to remote sensing signal, is the mass of water per unit ground area (expressed in g.m-2). Nevertheless, the retrieval of this variable can be challenging due to the potential confusion with soil moisture effects (Xue, 2017), (Yeqiao, 2020).

The phenology of vegetation through indices is two types of measures used to study and monitor plant growth and productivity. The phenology of vegetation is based on the timing and appearance of different stages in the plant life cycle. For example, the start of the growing season, the peak of vegetation growth, and the end of the growing season can all be detected through vegetation and biophysical indices.

Biophysical indices, on the other hand, are based on the physical properties of plants, such as their reflectance, absorption, and transmittance of light. These indices are often used to estimate plant productivity, biomass, and other physical characteristics. Both vegetation and biophysical indices can be measured using remote sensing techniques, such as satellite images. These indices are valuable tools for studying and monitoring changes in plant growth and productivity and can be used to understand the impacts of climate change, land use changes, and other environmental factors on vegetation.

2.2.2 Corine land cover data

The CLC2018 dataset is one of the products of the Corine Land Cover (CLC) initiative, which falls under the Copernicus Land Monitoring Service and pertains to the land cover and land use status of the year 2018. The CLC program has a rich history and was previously known as the "CORINE Land Cover Programme", which is managed by the European Environment Agency (EEA) (https://land.copernicus.eu). This initiative aims to provide consistent, detailed, and thematically precise information on land cover and changes in land cover throughout Europe. The resulting European database is based on standardized methodology and nomenclature, with a 3-level hierarchical classification system that includes 44 classes. For the study area was identified 5 land use classes included in 3 level system classification: 211 (Non-irrigated arable land), 231 (Pastures), 242 (Complex cultivation patterns), 243 (Land principally occupied by agriculture, with significant areas of natural vegetation), 411 (Inland marshes) (Ursu et al., 2006).

3. Results

The current status of remote sensing in Natura 2000 monitoring is illustrated through case studies from European and national projects, which demonstrate the practical applications of remote sensing in monitoring Natura 2000 sites (Nicoară et. al., 2004).

In this site are the following natural habitats of community importance: 62C0 (Ponto-Sarmatian steppes), and 40C0 (Ponto-Sarmatian deciduous thickets). In habitat 40C0*, with an area of 1.7 ha, the land is occupied by thickets consisting of dovecot, hawthorn or dwarf almond, sometimes impenetrable, being usually unused; in habitat 62C0*, with an area of 579 ha, the land is used as pasture and hay (ROSCI0058 Dealul lui Dumnezeu site management plan).

3.1. Vegetation and Biopysical indices

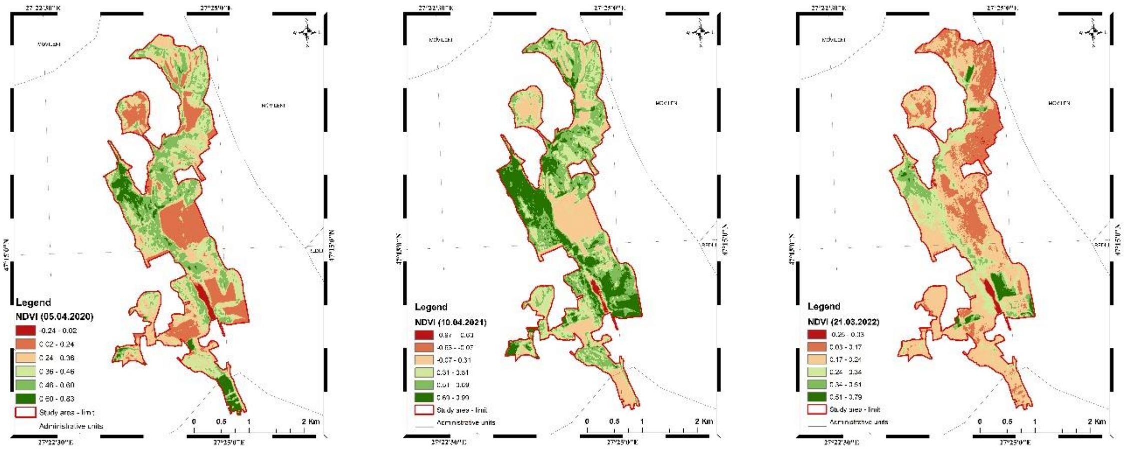
The site ROSCI0058 "Dealul lui Dumnezeu" is located in the hilly plain of Jijia-Bahlui, part of the Iasi county. Site ROSCI0058 overlaps the upper and middle valleys of the Roșior stream, left tributary of the Bahlui river. The general orientation of the valley in the North-South direction is complicated by the branching of the tributaries of the Roșior stream in all directions, which gives the valley a dendritic appearance, much more branched than in the case of the David and Mârzești valleys. On the general North-South background, the orientation of the upper valley can be observed in the NE-SW direction, and of the middle valley in the NW-SE direction. The aspect of the valley is that of a shelter basin, developed through selective erosion, framed by interfluvial ridges extended towards the localities of Horlești, Ursoaia, Iepureni and Avântu, with altitudes close to 100-130 m.

The analysis was carried out over three seasons, taking into account the phenological phases of the plants: spring, summer and autumn. For each of the three seasons, the following vegetation and biophysical indices were analyzed: NDVI, LAI, FAPAR, FCOVER, CAB and CW.

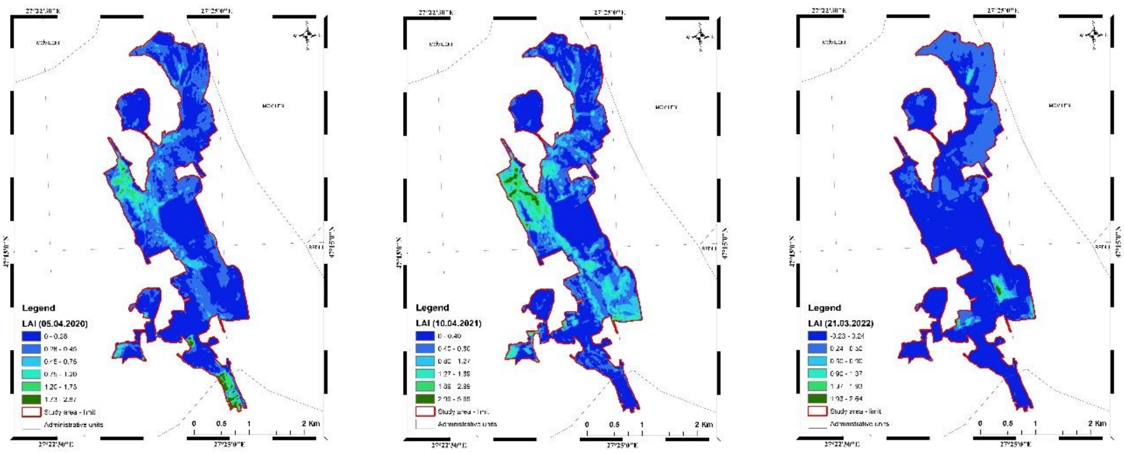
3.1.1. Spring season

Figure 4 shows the spatial distribution for studied vegetation and biophysical indices for the site ROSCI0058.

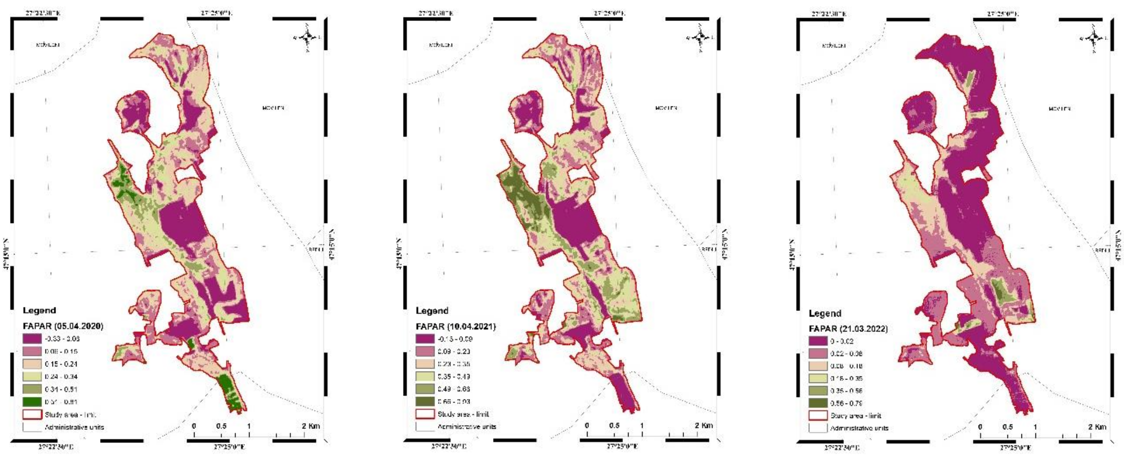
In this case, the vegetation has high values only for 10.04.2021 due to high precipitation and temperature values. The 2022 year is a particular one, with low values which also caused a vegetation fire on March 23 (Figure 5b).



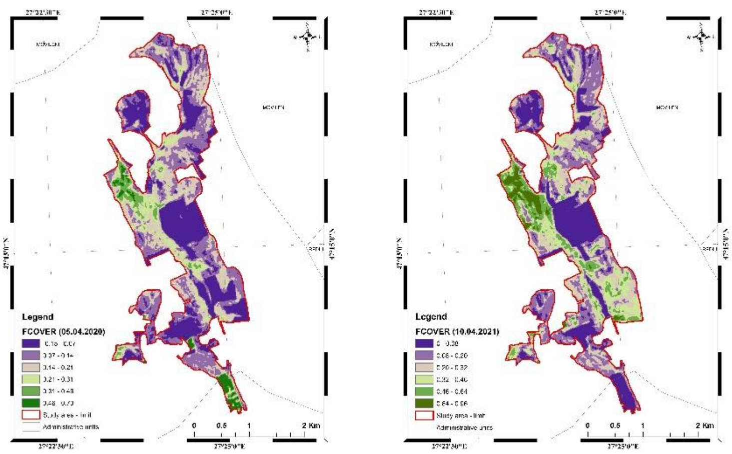
NDVI



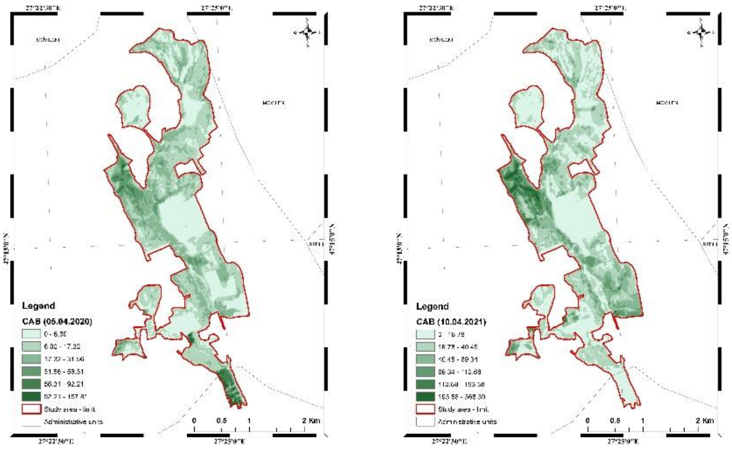
LAI



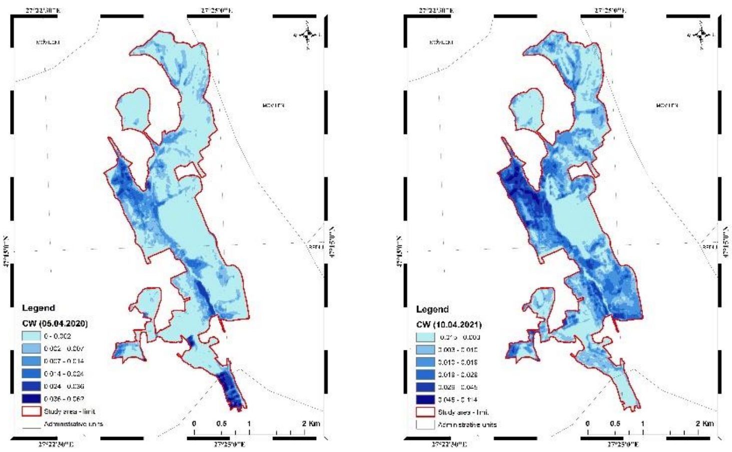
FAPAR



FCOVER



CAB



CW

Figure 4. Spatial distribution of vegetation and biophysical indices for spring season (2020 - 2022)

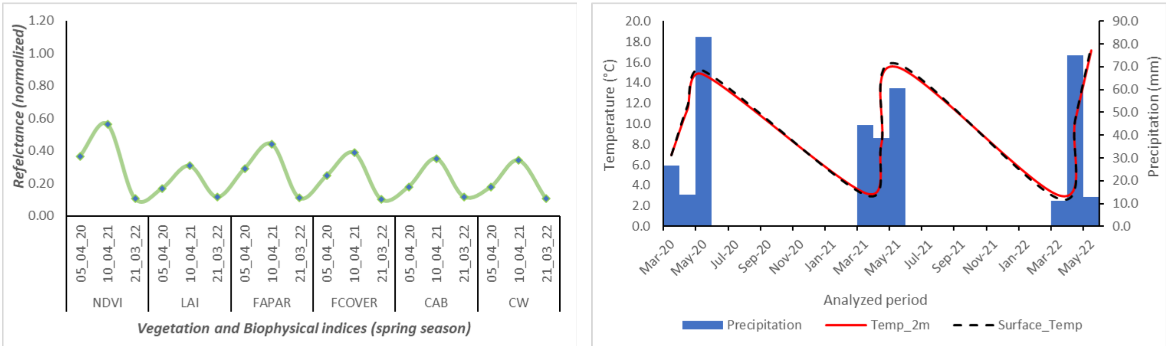
In table 3 it can be observed the minim and maxim values for the vegetation and biophysical indices.

Also, it can be observed that all indices have high values for spring 2021, followed by 2020, and 2022. The SE part of the site, due to the valley aspect, with more than a 15-degree slope has the lowest values for all indices.

Table 3. Range of variation of spectral indices within the spring season

Spectral indices / Year	NDVI		LAI		FAPAR		FCOVER		CAB (g/cm²)		CW (µg/cm²)	
	MIN	**MAX**	**MIN**	**MAX**	**MIN**	**MAX**	**MIN**	**MAX**	**MIN**	**MAX**	**MIN**	**MAX**
2020	-0.24	0.83	0	2.87	-0.33	0.81	-0.15	0.73	0	157.81	0	0.062
2021	-0.97	**0.99**	0	**5.69**	-0.13	**0.93**	0	**0.96**	0	**368.39**	-0.015	**0.11**
2022	-0.25	0.79	-0.23	2.64	0	0.79	0	0.74	-18.69	130.02	-0.027	0.076

In Figure 5a, it can be observed the normalized values for all analyzed indices. The values show a pick for all indices, for spring 2021, which can be correlated with the b figure, where the temperature values sustained the reflectance values: high-temperature values for 2021, followed by 2020, and lowest in 2022 (Figure 5a).



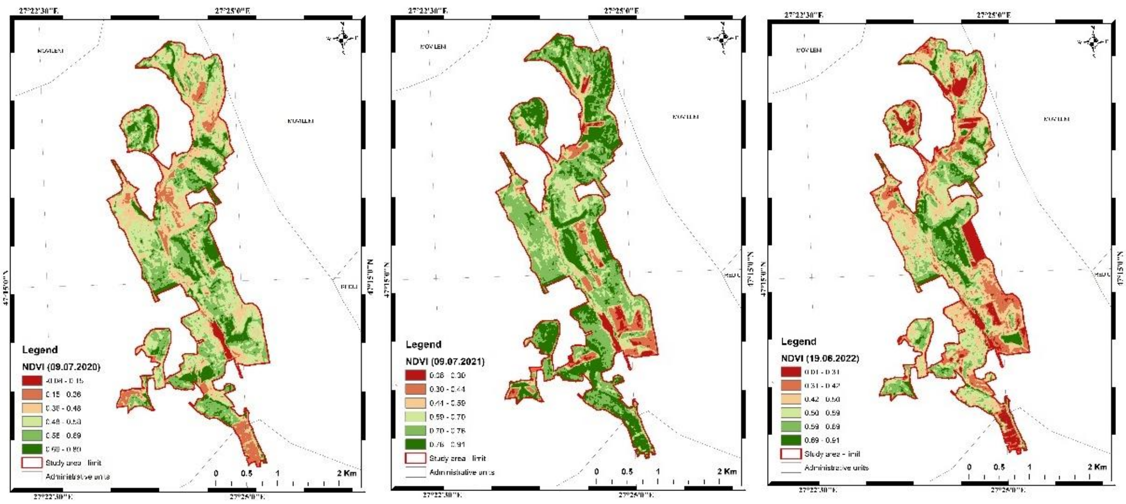
a) b)

Figure 5. The spring season results: a) Normalized spectral indices; b) Climatic features (precipitation and temperature) for ROSCI0058 site.

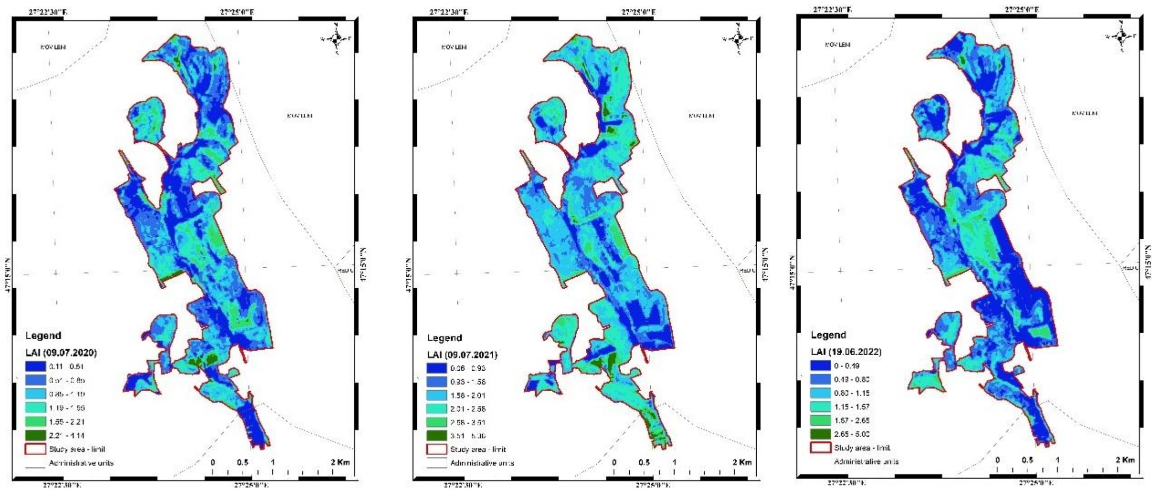
3.1.2. Summer season

Figure 6 shows the spatial distribution of the vegetation and biophysical indices from 2020 to 2022 and table 4 summary the range of variation of spectral indices during the summer season.

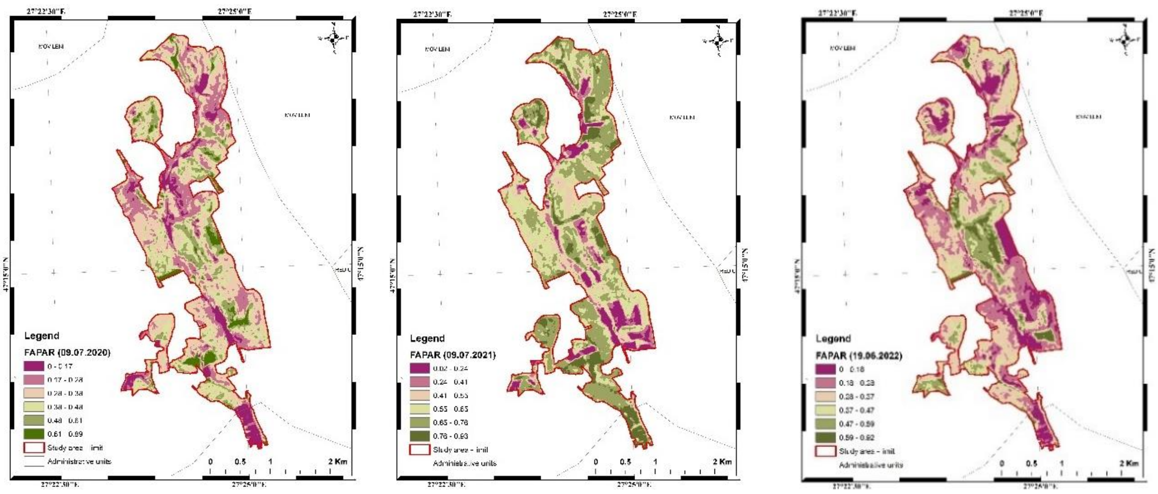
The values for all indices are approximately decreased from southeast to northwest. The southwestern, southeast, and south part of the site mainly comprises bare land and non-irrigated arable land areas with dry climatic conditions and poor vegetation ecological conditions, resulting in low indices values.



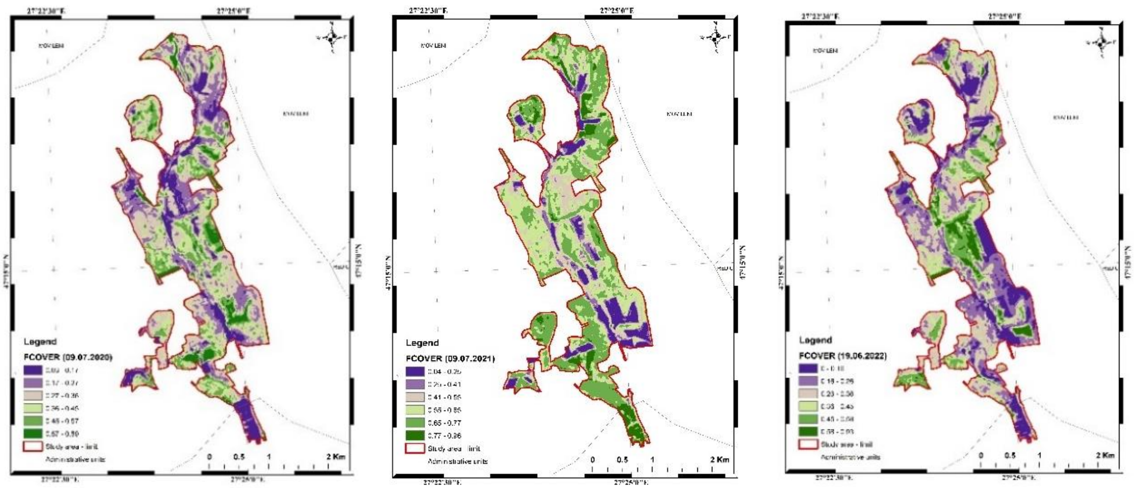
NDVI



LAI



FAPAR



FCOVER

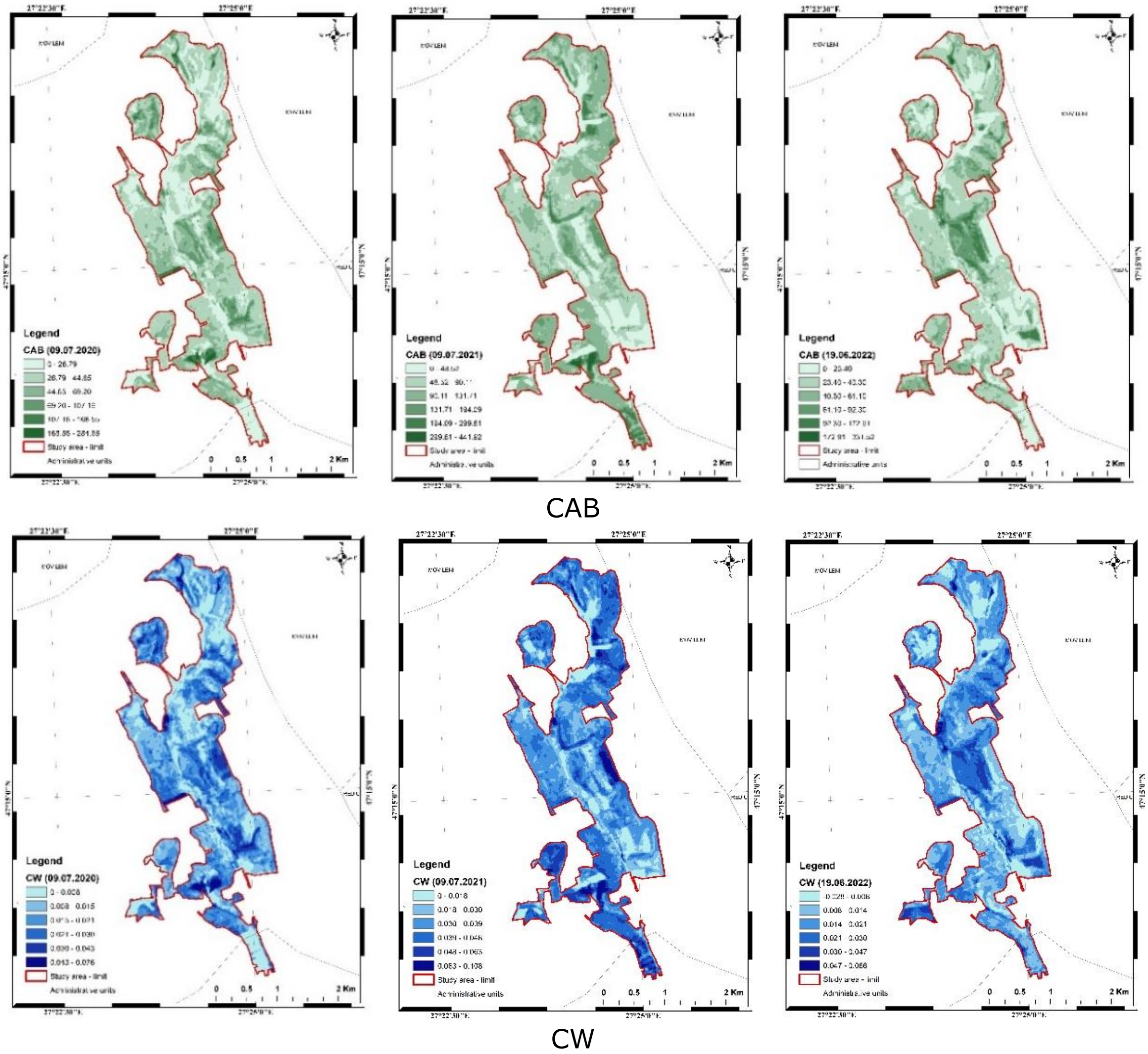
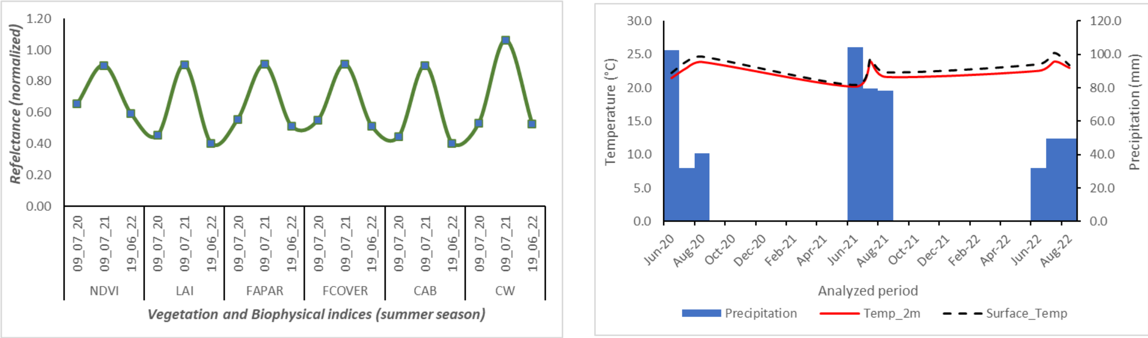


Figure 6. Spatial distribution of vegetation and biophysical indices for summer season (2020 - 2022)

Table 4. Range of variation of spectral indices within the summer season

Spectral indices / Year	NDVI		LAI		FAPAR		FCOVER		CAB (g/cm²)		CW (µg/cm²)	
	MIN	**MAX**	**MIN**	**MAX**	**MIN**	**MAX**	**MIN**	**MAX**	**MIN**	**MAX**	**MIN**	**MAX**
2020	0.08	0.89	0.11	4.14	0	0.89	0.03	0.89	0	284.65	0	0.076
2021	0.08	**0.91**	0.06	**5.36**	0.01	**0.93**	0.04	**0.96**	0	**441.92**	0	**0.108**
2022	0.01	0.91	0	5	0	0.92	0	0.93	0	331.52	0.028	0.086

Spatially, the non-vegetation cover was distributed mainly in the watercourse and lake area and the areas with high slopes, while healthy vegetation cover was in the rest of the territory. The annual variance of the vegetation and biophysical indices shows as was expected, a pick for 2021 year that can be explained by high values of temperature (monthly average 20°C) and precipitation (100 mm) (Figures 7a, b).

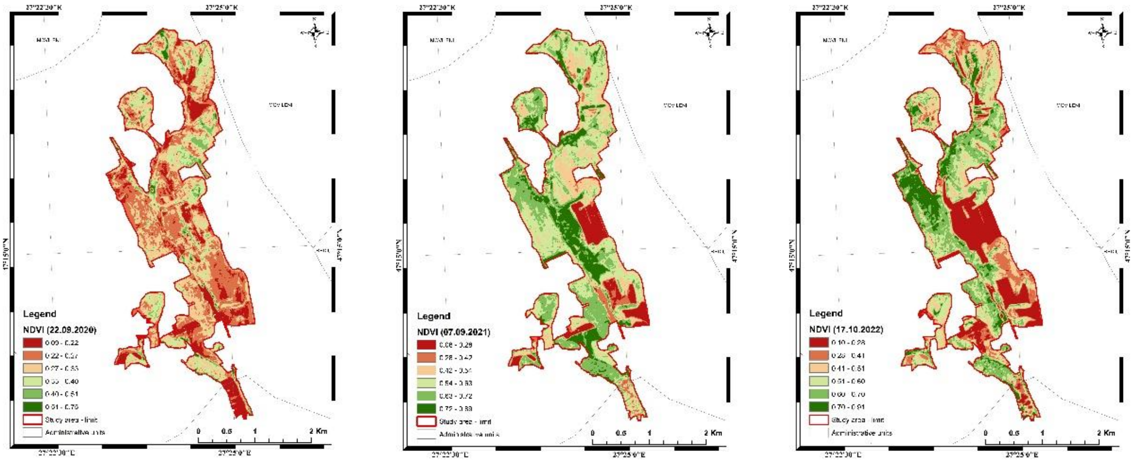


a) b)

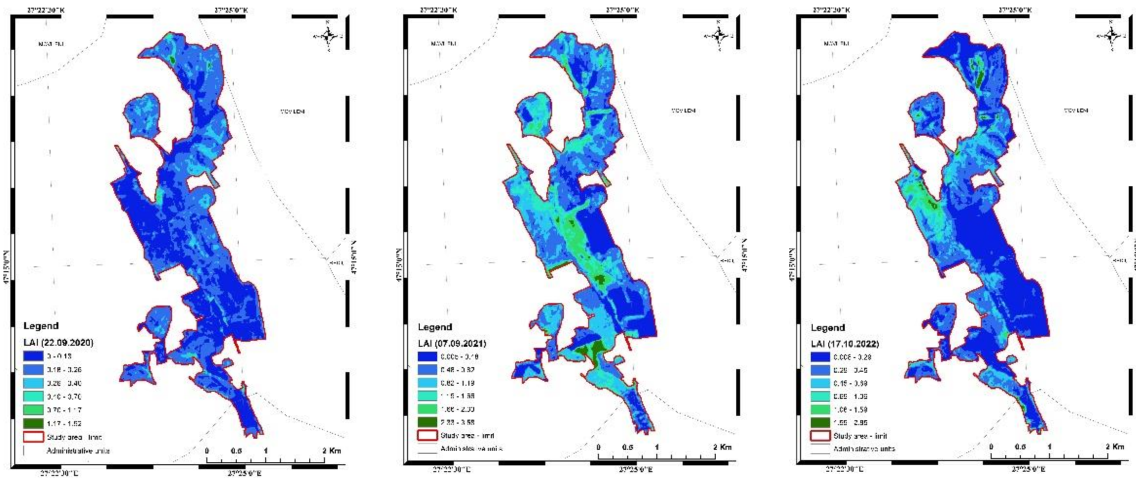
Figures 7. The summer season results: a) Normalized spectral indices; b) Climatic features (precipitation and temperature) for ROSCI0058 site.

3.1.3. Autumn season

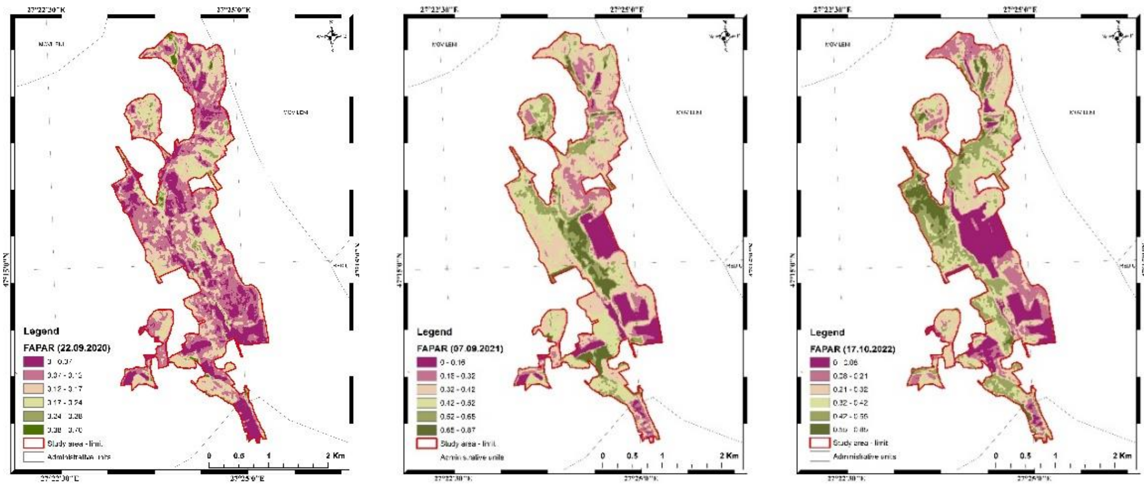
Due to the spatial distribution of land use, it could be observed that in certain areas of the site, the vegetation is more developed in the plateau area, but especially in the predominant area with arable land mixed with natural vegetation.



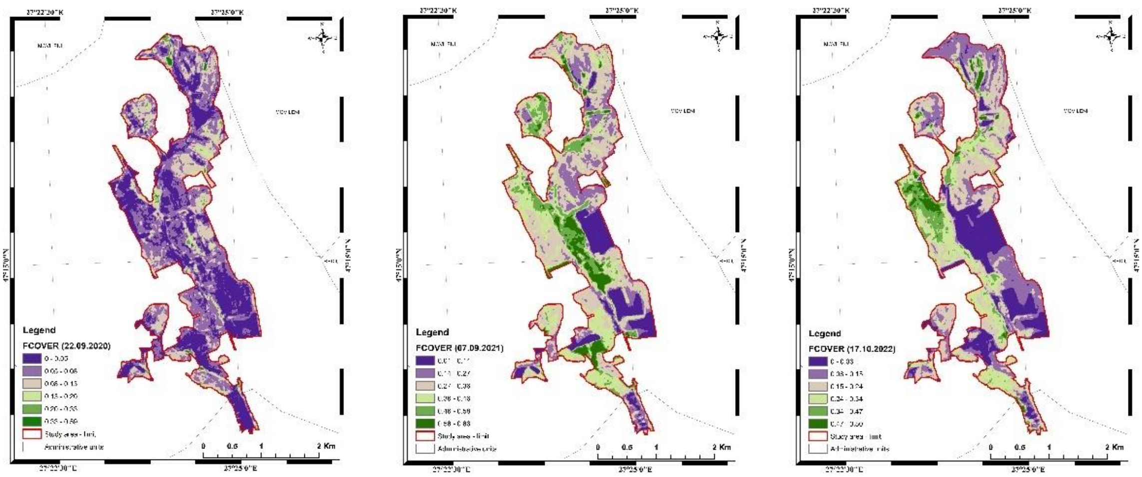
NDVI



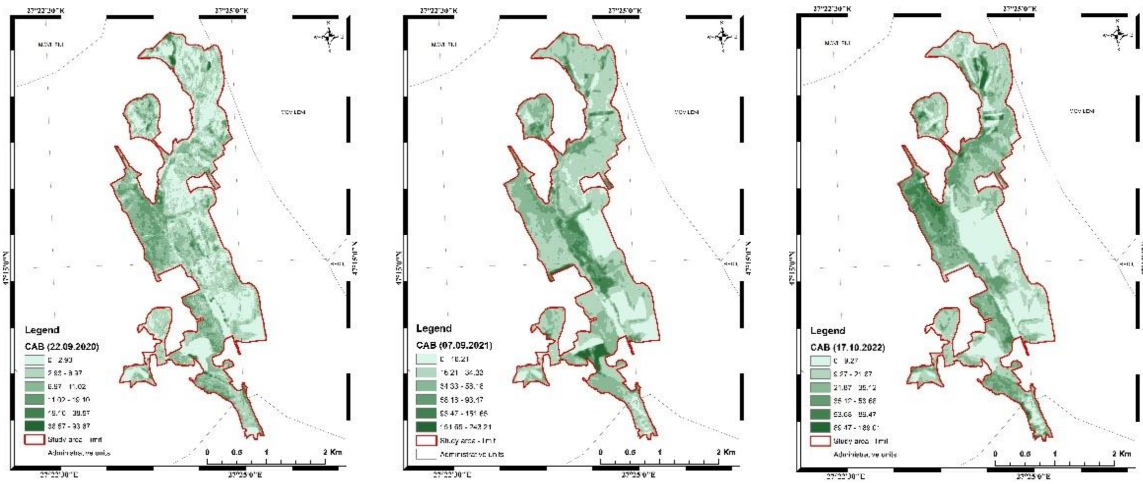
LAI



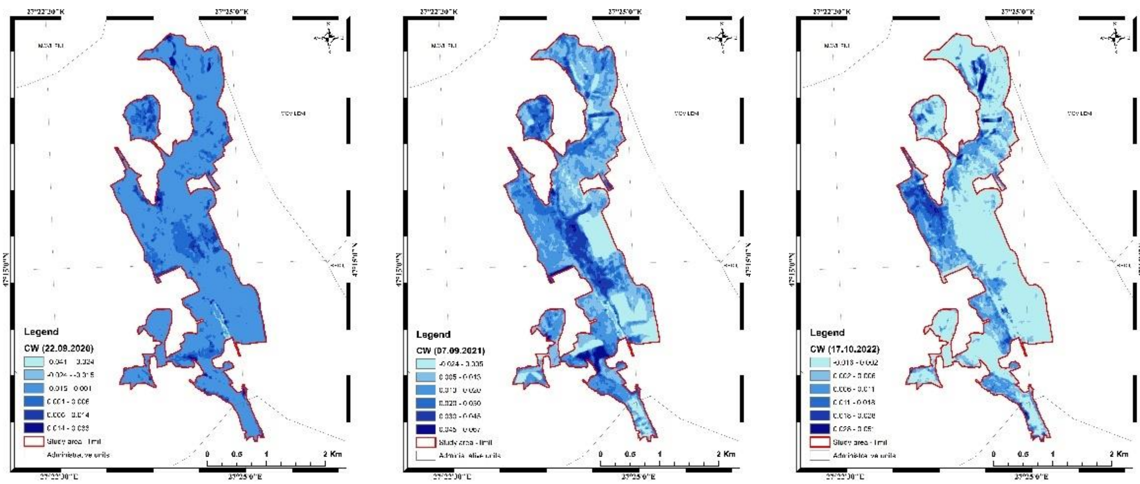
FAPAR



FCOVER



CAB



CW

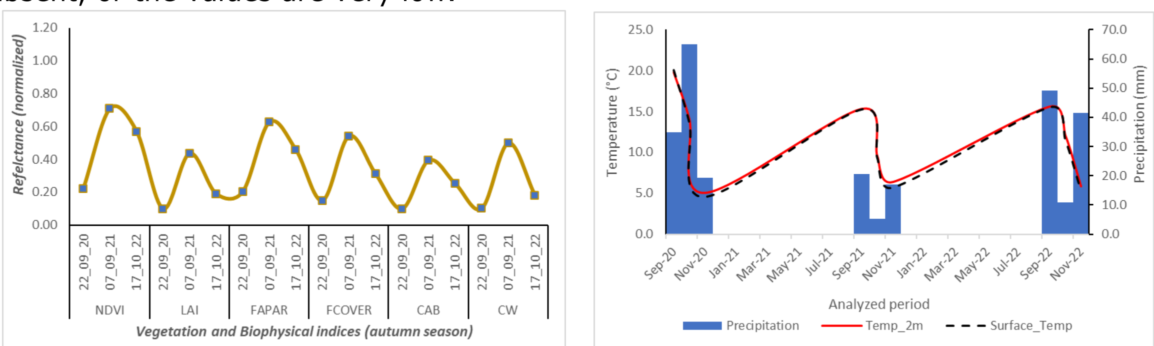
Figure 8. Spatial distribution of vegetation and biophysical indices for autumn season (2020 - 2022)

Based on figure 8, the vegetation spatial distribution in "Dealul lui Dumnezeu" site, for autumn season show the following values, while table 5 summary the range of variation of spectral indices during this season.

Table 5. Range of variation of spectral indices within the autumn season

Spectral indices / Year	NDVI		LAI		FAPAR		FCOVER		CAB (g/cm^2)		CW ($\mu g/cm^2$)	
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
2020	0.09	0.75	0	1.92	0	0.70	0	0.59	0	93.67	0.041	0.033
2021	0.08	**0.89**	0.005	**3.58**	0	**0.87**	0.001	**0.86**	0	**243.21**	0.024	**0.067**
2022	0.10	0.91	0.008	2.85	0	0.85	0	0.80	0	169.01	0.016	0.051

The phenological development of seasonal vegetation typically follows a predictable pattern based on the changing seasons and climate conditions. In figures 9 (a, b), it can see the variation in the values of the vegetation and biophysical indices for the autumn season, where due to the temperatures starting to drop (with a monthly average of 19.8 degrees - 2020, 15.3 in 2021 and 12.1 in 2022), the senescence phase of the plants appears, also observed in figure 8. The distribution of the vegetation was correlated also with the slope and aspect, where the slope is more than 10 degrees, the vegetation it's absent, or the values are very low.



a) b)

Figure 9. The autumn season results: a) Normalized spectral indices; b) Climatic features (precipitation and temperature) for ROSCI0058 site.

3.2. Corine land cover distribution

The Corine land cover distribution for 2018 year (figure 10) indicate the presence of multiple type of land use from the level 2 class: *Arable land* (211): 298.49 ha, *Pasture* (231): 144.21 ha, *Heterogeneous agricultural areas* (242, 243): 229.44 ha, and *Inland wetlands* (411): 35.49 ha. Among all the land use types present on the site, some areas are more affected than others presenting a very low vegetation level for the phenological period.

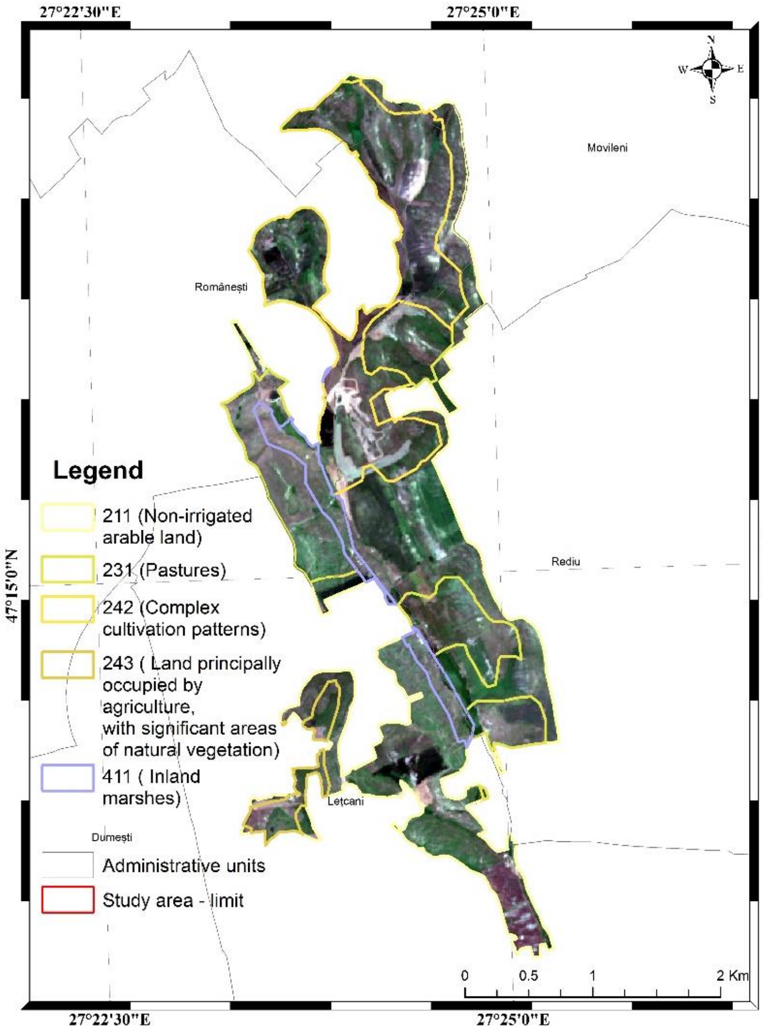


Figure 10. Land-use distribution for ROSCI0058 site (CLC 2018)

In the SE, NW and central of the site the slope varies between 7.5 - 17.5 degrees being associated with the 231 land-use type, while in the SW, the slope is between 7.5 - 12.5 degrees and 243 land use type. In the valley area, associated with 411 land use, is the lake area and the Rosior River with a slope between 0 - 5 degrees and specific hygrophilous vegetation.

From the analyzed time series, the year 2021 stands out, recording in the spring season, for pasture (231) reflectance exceeding 0.60 for all indices (Figure 11a), while in summer, reflectance values were higher than 0.80 for heterogeneous agricultural areas (243) and inland (411) (Figure 11b), to 0.40 - 0.70 in autumn for pastures (231) and agricultural areas (243). A particular situation being observed in 2022 when reflectance ranged between 0.30- 0.80 for the 411 uses (Figure 11c).

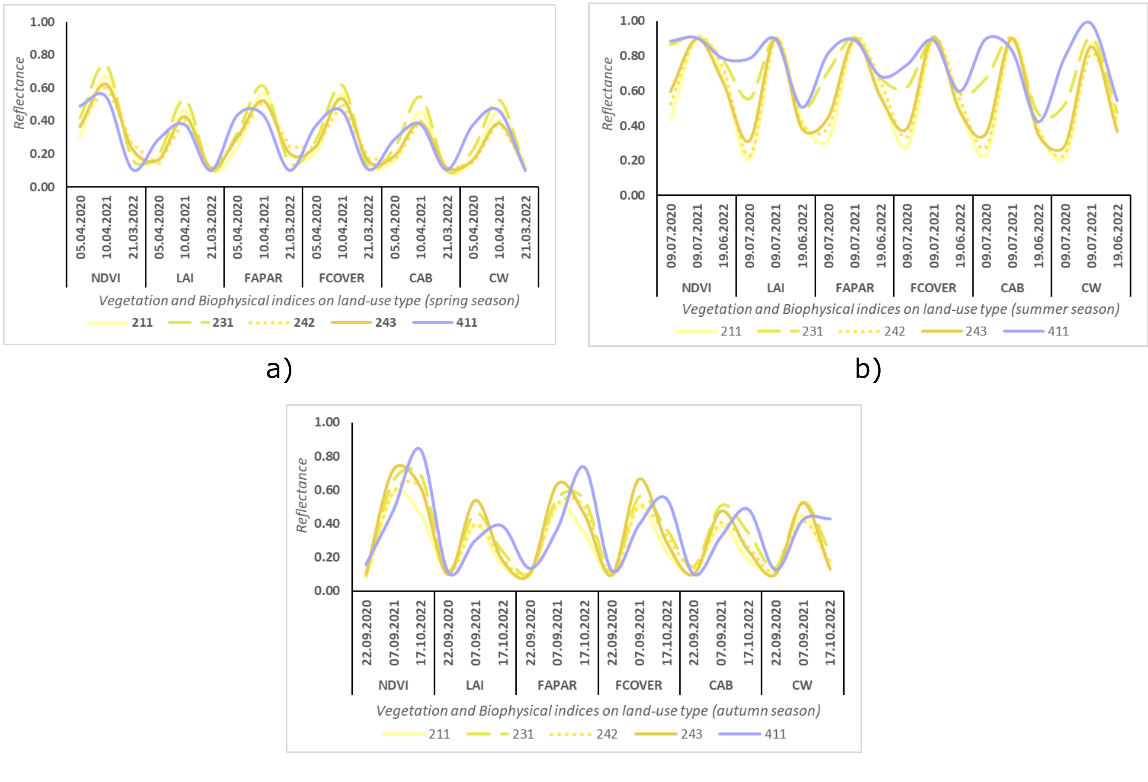
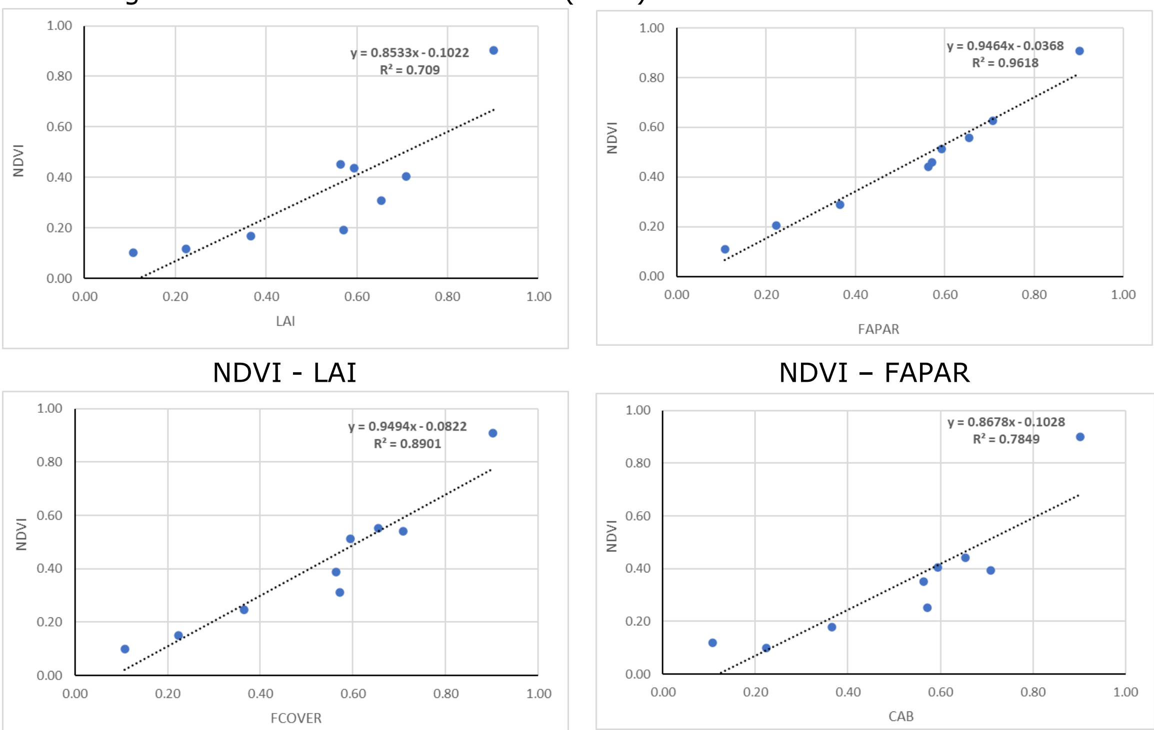


Figure 11. Dynamics of spectral vegetation and biophysical indices in relation to land use type: spring season; b) summer season; c) autumn season

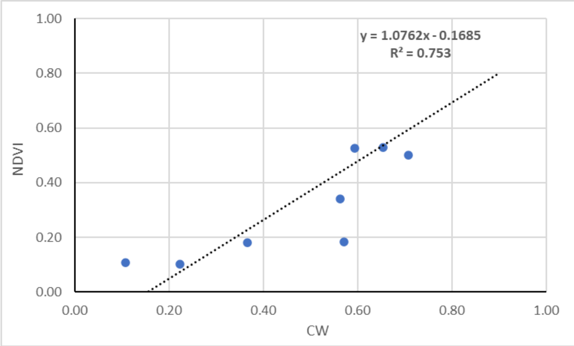
4. Discussion

Between the normalized differential vegetation index and all biophysical indices calculated in this study a linear regression was applied, can be seen in Figure 12. The coefficient of determination - R2 records the lowest value between NVDI and LAI (0.70), and the highest between NDVI and FAPAR (0.96).



NDVI - LAI NDVI – FAPAR

NDVI - FCOVER NDVI – CAB



NDVI – CW

Figure 12. Regression relationship between the vegetation index (NDVI) and the biophysical indices

The relationship between NDVI and LAI, indicated that as vegetation density and canopy cover increase, both indices tend to increase as well. However, the exact relationship between NDVI and LAI can vary depending on factors such as vegetation type, vegetation structure and soil background. In contrast, NDVI is related to FAPAR by a linear relationship, NDVI being a good estimator of FAPAR, which allows that the estimation of changes in FAPAR can be made based on changes in NDVI and vegetation productivity respectively. In areas with sparse vegetation cover or a mixture of vegetation and bare soil, high NDVI values do not necessarily correspond to high FCOVER values, as the NDVI signal may be affected by soil reflectance. In addition, in areas with a dense vegetation cover, the relationship between NDVI and FCOVER may be influenced by the vertical structure of the vegetation canopy, and it is recommended to consider different vegetation types. In the case of the regression between NDVI and CCC, the main influencing variables are: vegetation type, environmental conditions. In water-stressed or nutrient-deficient areas, the correlation between NDVI and CCC may be low. In addition, NDVI is sensitive to factors such as soil background and atmospheric effects, which can introduce noise and variability into the relationship between NDVI and CCC. NDVI provides an estimate of total vegetation cover and biomass, while CCC focuses on the amount of water stored in the canopy. Therefore, although NDVI and CWC are related, they represent different aspects of vegetation water content and should be interpreted together with other information and environmental context to provide a comprehensive understanding of vegetation health and productivity.

5. Conclusions

Thanks to the development of science and technology, remote sensing can be used to monitor a protected area much more easily. Advances in remote sensing have facilitated the collection and dissemination of protected area information on an unprecedented scale and frequency. Promising new applications of remote sensing data have emerged, leading to more informed management. Vegetation and biophysical variables, including NDVI, LAI, FAPAR, FCOVER, CAB and CW, were derived from Sentinel-2 satellite imagery for the Dealul lui Dumnezeu site over three seasons from 2020 to 2022 across all phenological periods. NDVI is a widely used vegetation index that measures the amount and health of vegetation by analyzing near-infrared and red-light reflectance. NDVI varies with the seasons due to changes in vegetation growth, cover and leaf pigments. LAI is usually highest during the summer season, when plant growth is highest, and lowest during autumn, depending on vegetation type and location. Like LAI, FAPAR also varies with season due to changes in vegetation growth and leaf area. FCOVER is related to LAI and FAPAR, but provides a more direct measure of vegetation cover on the ground. FCOVER also varies with the seasons due to changes in growth and vegetation cover. Remote sensing can play a crucial role in characterizing and delineating species in and around protected areas, ultimately helping authorities to manage them.

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References

1. Ardeleanu, N.N.; Breabăn, I.G. (2021) Biodiversity policies, opportunities for restoring the economy. *Present Environment and Sustainable Development*, *15*(2), 161-169. https://doi.org/10.15551/pesd2021152013

2. Ciutea, A.; Jitariu, V. (2020) Thermal inversions identification through the analysis of the vegetation inversions occurred in the forest ecosystems from the eastern Carpathians, 14(2), pp. 29-42, https://doi.org/10.15551/pesd2020142002

3. CORINE Land Cover, Copernicus programme. Available online: https://land.copernicus.eu/pan-european/corine-land-cover (accessed on 23 April 2023).

4. Djmai, N.; Zhong, D.; Fernandes, R.; Zhou, F. (2019) Evaluation of vegetation Biophysical Variables Time Series Derived from Synthetic Sentinel-2 Images, Remote Sensing, 1547, pp. 1-18. http://10.3390/rs11131547

5. Garrigues, S.; Shabanov, N.V.; Swanson, K.; Morisette, J.T.; Baret, F.; Myneni, R.B. (2008) Intercomparison and sensitivity analysis of Leaf Area Index retrievals from LAI-2000, AccuPAR, and digital hemispherical photography over croplands. Agricultural and Forest Meteorology, 148, 1193-1209. https://doi.org/10.1016/j.agrformet.2008.02.014

6. Hojas-Gascón, L.; Belward, A.; Eva, H.; Ceccherini, G.; Hagolle, O.; Garcia, J.; Cerutti, P. (2015) Potential improvement for forest cover and forest degradation mapping with the forthcoming SENTINEL-2 program, Germany, International Symposium on Remote Sensing of the Environment (ISRSE), (47), 417-423. https://dx.doi.org/10.5194/isprsarchives-XL-7-W3-417-2015

7. Mărgărint, M. C. (2010) Utilizarea teledetecției în studiul geografic al teritoriului județului Iași, Editura Universității Alexandru Ioan Cuza., 2010. Iași, 300p.

8. Muñoz Sabater, J. (2019) ERA5-Land hourly data from 1950 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). https://doi.org/10.24381/cds.e2161bac

9. Nicoară, M., Bomher, E. (2004) Ghidul ariilor protejate din județul Iași, S.C. Tipografia Moldova, Iași.

10. Nicoară, M., Bomher E. (2010) Conservarea biodiversității în județul Iași, Editura Pim, Iași, 2010, pp. 83-84.

11. Ursu, A.; Stoleriu, C.; Sfîcă, L.; Roşca, B. (2006) Adaptarea nomenclaturii Corine Land Cover la specificul utilizării terenului în România, Geographia Technica, 1, 1, pp. 193-198.

12. Ursu, A.; Nicoară, M. (2013) Ghidul siturilor Natura2000, Dealul lui Dumnezeu, Pădurea și pajiștile de la Mârzești, jud. Iași, Editura Studis, Iași, pp. 24-25.

13. Xie, Q.; Dash, J.; Huete, A.; Jiang, A.; Yin, G.; Ding, Y.; Peng, D.; Hall, C. C; Brown, L.; Shi, Y; Ye, H.; Dong, Y; Huang, W. (2019) Retrieval of crop biophysical parameters from Sentinel-2 remote sensing imagery, Int J Appl Earth Obs Geoinformation 80 187–195. https://doi.org/10.1016/j.jag.2019.04.019

14. Xue, J.; Su, B. (2017) Significant Remote Sensing Vegetation Indices: A review of Developments and Applications, Journal of Sensors. https://doi.org/10.1155/2017/1353691

15. Yeqiao, W.; Zhong, L.; Yongwei, S.; Yuyu, Z. (2020) Remote sensing applications in monitoring of protected areas, 1370. https://doi.org/10.3390/rs12091370

16. Weiss, M.; Baret, F.; Myneni, R.; Pragnère, A.; Knyazikhin, Y. (2000) Investigation of a model inversion technique for the estimation of crop characteristics from spectral and directional reflectance data. Agronomie, 20, (1)3-22. https://doi.org/10.1051/agro:2000105

17. Climate Data Store. Available online: https://cds.climate.copernicus.eu/ for temperature and precipitation data (accessed on 1 March 2023).

18. Copernicus Land Monitoring Service. Available online: https://land.copernicus.eu/ (accessed on 1/03/2023).

19. Copernicus Open Access Hub. Available online: https://scihub.copernicus.eu/ (accessed on 1/03/2023).

20. European Space Agency. Available online: https://sentinel.esa.int/ (accessed on 1 March 2023).

21. ROSCI0058 Dealul lui Dumnezeu site management plan.