Drought monitoring mapping by using satellite remote sensing: Study Case

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***Abstract*— Drought is the consequence of the absence of water, and the many variables that produce the meteorological drought (as the reduction of precipitation, climate changes, and surface temperature between others) are well understood. When this Meteorological drought is persistent, it leads to a reduction of soil moisture or agricultural drought which consequently reduces the stream of rivers, lake levels, and underground flows creating a hydrological drought. In growing crops, the water deficit reduces the production efficiency of the enzymes in charge of the photosynthesis process of the plants which harms the farm's production inducing a socioeconomic drought. European countries went through one of the most droughted periods of the last centuries during the summer of the year 2022 increased by the frequent heatwaves and Hungary was not exempted from its consequences, where the higher drought index is commonly observed in the northern, western, and central section of the country. In the study, satellite images were used to map the state of vegetation. We monitored the effect of drought on crop-growing soils based on the statistical analysis of vegetation indices calculated from images, where the Normalized Difference Vegetation Index (NDVI) values are notably increasing until the 21st of Jun of the year 2022 reaching a maximal value of 0,6012 in one of the analyzed fields before it starts decreasing to a minimum observed value of 0.3209 in the same field after a period of thirty-seven days due to lack of water.**

Keywords—*Crop Growing, Drought, Remote Sensing, Image Index Analysis*

I. INTRODUCTION

The dynamics of the soil-atmosphere moisture interaction start when the land content of water naturally evaporates, rising to the atmosphere, where these molecules lose energy, giving place to condensation while the temperature decreases, creating local cumulus of water, and finally precipitate back to the soil closing this dynamic cycle. When the field of study presents an anomalous leak of this precipitation during an extended time (known as a meteorological drought), other sources of water, such as lakes, rivers, or underground flows decrease their levels or caudal [1]. This hydrological drought eventually influences the plant metabolism, the stress produced in the crop impacts different levels of the vegetation modifying physiological and biochemical features, i.e., rooting, growing, and breeding processes considered as an agricultural drought [2], [3]. The effects of soil drought have shown consequences all around the Earth's surface as example, the drought that California – United States of America – suffered between the years 2012 – 2015 registered an economical loss of $810M only in the farming sector [4]. On the other hand, the European continent passed through the most drought summer of the last centuries according to the Global Drought Observatory (GDO) analytic report of August 2022 due to the frequent heatwaves that crossed the continent.

The availability of different Remote Sensing (RE) techniques provides a tool to support the decision-making activity within the involved agricultural processes, from the land preparation prior to seeding until the harvest time of the crop [5]. This RS trend presents a huge rising pivot in the last 20 years with all the unmanned aerial applications of this variety of systems i.e. UAV's or dedicated satellites implemented to compile enough information to give a clear idea of the current health state of the analyzed field, allowing farmers to react on time and optimize the crop production while increasing the usage efficiency of resources as water.

Multi-spectral remote sensed imagery has become one of the most common practices to obtain new images from the combination of two or more frequencies for information extraction [6] to indicate canopy changes due to water stress. One of the earliest RS analytical products is the NDVI used to simplify the analysis of the multi-frequency images resulting from the usage of the near-IR band which is highly effective for expressing vegetation status and quantified vegetation attributes [6].

II. SATELLITE IMAGES AND DATA ANALYSIS

Multispectral ESA Sentinel-2 satellite images acquired from the ESA Sentinel Scientific Data Hub were used in this study. The investigation period was between June and August 2022. A total of 13 cloud-free images were available, but after preliminary interpretation, 7 of them were selected for further processing. Meteorological (the amount and the intensity of precipitation) data were considered in the selection. The characteristics of the data used in the research are included in Table 1.

TABLE I. REMOTE SENSING AND METEOROLOGICAL DATA

Dataset	Parameter	
	Data type	***Acquisition date***
Sentinel-2	Spectral resolution VIS, NIR, SWIR (bands: 3, 4, 8, 12)	03, 11, 21. June 2022 06, 18, 21, 28 July 2022
Meterological station	Precipitation accum. total	May (13 mm) June (49 mm) July (17 mm) August (67 mm)

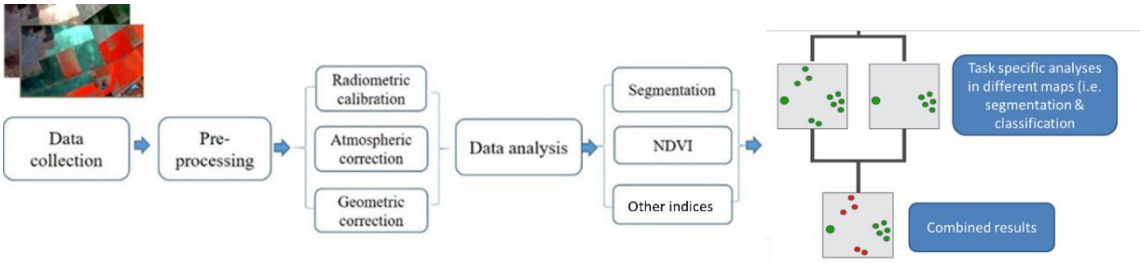


Fig. 1. Satellite data analyses steps for mapping drought with OBIA

Technically, this research was performed in eCognition Developer software environment. The images and the time series analysis were processed using object-based image analysis (OBIA). Workflow illustrating the main steps of data analyses for drought monitoring is depicted in Figure 1.

The data extraction includes the following steps: data pre-processing, multi-level image segmentation, delimitation of indices, and vegetation index-based classification. It is important to note that the Sentinel-2 Level-1C processing includes radiometric and geometric corrections including ortho-rectification. Calculation of the TOA (the top-of-atmosphere) reflectance also occurs in this process. A hierarchical framework was used to identify the boundary of study areas at a super-object level and determine the unit of investigation (20 m) at the second level for mapping the status of maize.

After pre-processing, vegetation indices like as NDVI, RIATO, and NDWI were determined. The most common vegetation index used in the water stress models is the NDVI. Reflectance at the red band (B4: 665 nm) and the near-infrared (B8: 842 nm) were used to calculate the NDVI. The classification results are based on NDVI threshold value to classify non-vegetation, low vegetation (poor quality), and high vegetation (good quality).

III. Calculation of NDVI index values and time series analysis

The NDVI index is the most widely used vegetation index in scientific research and in practice, the analysis of its value makes it possible to determine the developmental stage and condition of plants. To calculate the NDVI values, the reflectivity values are used recorded in the red (RED) and near-infrared (NIR) spectrum. The method of calculating the NDVI index is as follows:

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

By measuring the reflectance of the plants at various wavelengths, it is possible to collect plenty of information about the status and condition of the plants. The reflectance of light spectra depends on the land cover type (plant, soil types), water content within tissues, and other intrinsic factors. The reflectance of vegetation is low in the blue and red regions of the visible spectrum, due to absorption by chlorophyll for photosynthesis. It has a peak at the green region which gives rise to the green color of vegetation. In the near infrared (NIR) region, the reflectance is much higher than that in the visible band due to the cellular structure in the leaves. In the mid infrared (SWIR) there are more water absorption regions. Those regions are used to examine correlation between root zone soil moisture and the vegetation status. Based on RED, NIR and SWIR bands different indices are calculated to quantify plant vigor and relate it to root zone soil moisture. The soil moisture status influences the vegetation water status and thereby changes the spectral characteristics of the vegetation (Figure 2).

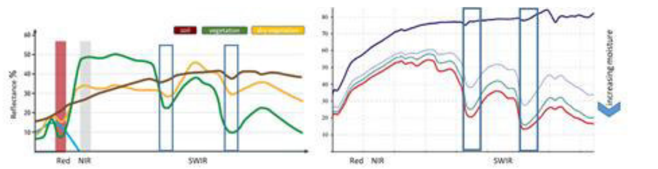
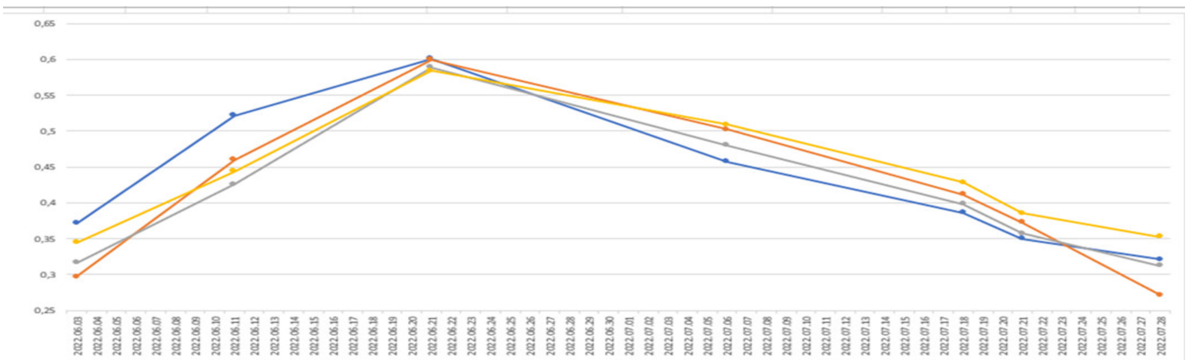


Figure 2. Spectral reflectance of vegetation and soil with different levels of water content (yellow line: dry vegetation). The spectral bands used to calculate the indices are highlighted. [7]



	2022.06.03	2022.06.11	2022.06.21	2022.07.06	2022.07.18	2022.07.21	2022.07.28
48/b	0,3716	0,5219	0,6012	0,4571	0,3862	0,3501	0,3209
47/c	0,2967	0,4603	0,5995	0,5022	0,4117	0,3731	0,2715
47/b	0,3165	0,4259	0,5889	0,4802	0,3985	0,3574	0,3126
49	0,3443	0,4439	0,584	0,5088	0,4285	0,3855	0,3524

Figure 3 NDVI values change for the period of 2022.06.03-07.28 for four different fields of maize.

NDVI values range from -1 to 1. NDVI values close to -1 occur in areas covered by water. Values ranging from -0.1 to 0.0 occur in areas of exposed soil without vegetation cover 0.0 to 0.33 occur in areas covered with poor vegetation or dry vegetation. NDVI index values ranging from 0.33 to 0.66 are characteristic of areas covered with vegetation of average condition. Values NDVI index above 0.66, are characteristic of plants in good condition being at the highest stage of development. The NDVI thresholds describing the different quality of vegetation were selected based on the literature and on field surveys. In this work we considered the results of image analyses of previous years with adequate water supply and maize growing stages. The field work was carried out with the participation of the crop production manager.

During the study, the analysis of the values of NDVI indicators was done for maize cultivation in the period from June to the end of August 2022. The calculation of NDVI index values was done for all images and the minimum, maximum, and average values were determined within the studied fields. In order to determine the impact of drought on the vegetation condition, the NDVI change analysis was done within examine period (Figure 3), as well as a comparison with each value of the NDVI indices for the corresponding months in 2019 (Figure 4).

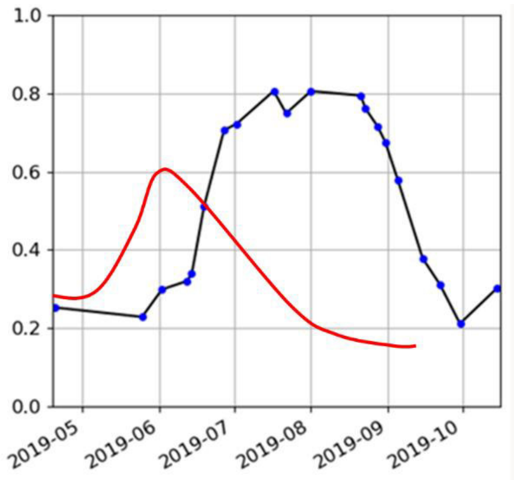


Figure 4. NDVI values change for the years 2022 (red line) and 2019 (blue line)

The calculated NDVI values exposed in the Figure 3 shows a decreasing tendency after the 21.06.2022 compared with the NDVI index values obtained the previous year (2019) in the corresponding months, when there was sufficient water supply for plant growth, with notable increasing numbers measured until the end of August reaching values above 0.8 as can be observed in blue dots on the Figure 4, in contrast with a maximum of 0.6 calculated in the 2022 (Figure 4 red line) which represents a reduction of 25% in three years. The calculated values of the NDVI index allow us to conclude that for all analyzed months, lower NDVI index values occurred in 2022, influenced by the drought.

IV. Object-Based Classification

In the object-based classification process we used segmentation to determine objects and it is included the following steps:

A. Segmentation

- Chessboard segmentation using thematic layer (Level 1, fields identification)
- Chessboard segmentation 20 m units (Main Level, analysis level)

B. Object classification

- Spectral values of 4 bands
- NDVI

In the classification process the objects were assigned into tree classes: maize with poor, average and high condition. Due to the draught only a few segments (cells) of area were assigned into the 'high quality' category. After 21 June basically only the 'poor' (NDVI ≤0,35) category was detectable (Figure 5).

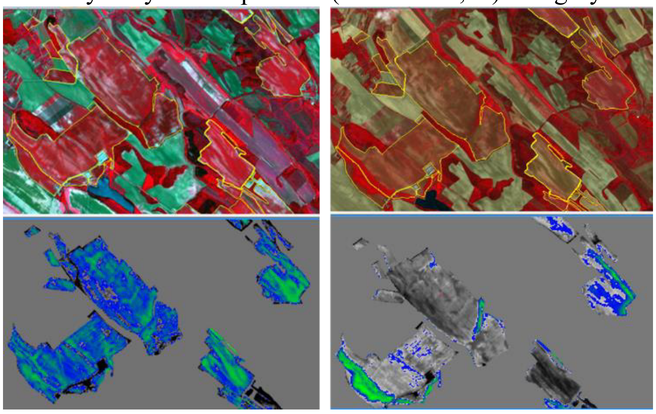


Figure 5 Sentinel2 images taken on 21.06.2022 and 07.28.2022 and NDVI based classification results. Pixels with the NDVI values of bigger than 0.35 are marked in color.

A view of the analyzed fields by using NDVI-based classification for two dates are presented in the Figure 5. The green-blue color indicates areas with NDVI values greater than 0.35.

V. Conclusion

The severe drought affecting many regions of Hungary since the beginning of the year has been further expanding and worsening as of early August. Dry conditions are related to a wide and persistent lack of precipitation combined with a sequence of heatwaves from May. One of the crops most affected by the negative precipitation anomalies in the three months ending on the end of August 2022 is maize. The NDVI index was applied to analyze the vegetation condition in this study area. According to the results, after 21 June the NDVI values show a sharp decline, while in the end of July the vegetation of most of the study area is completely dry.

On the other hand, the satellite Sentinel 2 provide data with relatively high spatial resolution (10-20 m) and high temporal resolution (3-5 days) observations of the Earth. So that remote sensing data has been increasingly used not only for large-area but also for within-field drought monitoring.

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