CHEMICAL ENGINEERING TRANSACTIONS
VOL. 107, 2023
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it
Guest Editors: Petar S. Varbanov, Bohong Wang, Petro Kapustenko

ISBN 979-12-81206-07-6; **ISSN** 2283-9216
DOI: 10.3303/CET23107108

Remote Sensing Supported Sustainable Forest Management in Hungary

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Climate change and the growing number of forest damage demanded a response from forestry professionals. Satellite-based remote sensing enables an environment-friendly way of forest monitoring as part of sustainable forest management. A novel forest monitoring approach was created in Hungary to utilize high-resolution Sentinel-2 satellite imagery, Google Earth Engine (GEE) cloud computing for the detection of forest disturbances remotely. The processing, analysing, and visualization of vegetation index (NDVI and Z NDVI) maps derived from satellite imagery took place online, in the cloud, for the period 2017–2023. My results indicated that the satellite imagery and ground-based reports provided suitable input for sustainable forest damage monitoring. In the seven-year-long period, the annual index changes corresponded to the experienced weather extremes and the Z NDVI values captured both the negative and positive forest health changes. The image classification was proved to be useful to show deviations from normal forest state since 67 % of pixels were in the forest damage category in 2022 when a historic drought occurred. In 2023 the regeneration was visible. The promising results and the flexibility of the GEE made it possible to enhance sustainable management and this system could be extended to include urban forests as well.

1. Introduction

Sustainable forest management is based on the balance of its three main components: ecological, economic, and socio-cultural (FAO, 2023). Maintaining the productivity of forests while conserving their biodiversity and offering a place for relaxing is a challenging combination of demands. Modern technologies support these efforts by providing forest monitoring methods (Franklin, 2001). Remote sensing by satellites is an effective tool for creating forest monitoring systems used for surveying forest health states to avoid degradation and deforestation – illustrated by land cover changes (Hossain et al., 2022) and forest management (Nandasena et al., 2022). Data processing in GIS programs helps to reveal forest characteristics. The main goal of the study is to explore the possibility of a remote-sensing way of forest monitoring, which is an environment-friendly and sustainable way of surveying since it is done remotely, freely and objectively on the computer instead of going to the field regularly.

Optical satellites are ideal tools for monitoring large areas by remote sensing (Vyvlečka and Pechanec, 2023). The Sentinel-2 satellites of the European Space Agency provide optical space imagery at 10x10 m spatial and 2-5 days temporal resolution for free of charge (ESA, 2023). From this satellite imagery, vegetation indices like the Normalized Difference Vegetation Index (NDVI) can be calculated. Forest ecosystem changes can be monitored on these maps at regular intervals using NDVI and its standardised version (Z NDVI).

These satellite images can be integrated into cloud services like Google Earth Engine (GEE), where imagery is stored, processed, analysed, and displayed in near real-time and online (Gorelick et al., 2017). The cloud-based system can be used to produce monthly and annual state maps, which are a composite of the best cloud-free pixels of a given period. Besides the index maps, a real-colour map can be created for visual interpretation, e.g., to distinguish a healthy forest with a green canopy from a yellowish or brownish forest indicating damage. In contrast, index maps are produced for one or more specific purposes to monitor the photosynthetic activity of forests (Khruschev et al., 2022). Afforestation can be monitored as well, which helps to mitigate the negative impact of climate change (Hanpattanakit et al., 2022).

Paper Received: 10 July 2023; Revised: 08 August 2023; Accepted: 09 November 2023
Please cite this article as: Molnár T., 2023, Remote Sensing Supported Sustainable Forest Management in Hungary, Chemical Engineering Transactions, 107, 643-648 DOI:10.3303/CET23107108

The importance of monitoring can be explained by weather extremes as well. Severe drought affected the whole of Europe, including Hungary, from spring to autumn 2022, causing the worst meteorological and climatological anomaly ever recorded in the Great Plain. The situation was most critical in spring, which has a particularly negative impact on the health of forests, as the beginning of the growing season in April and May is also the peak of the growing season. The spring to autumn period was analysed at the national and landscape level using high-resolution Sentinel-2 satellite imagery for the period 2017 to 2023. In the landscape-level analyses, one can also see changes within forest stands due to the high spatial resolution.

2. Materials and methods

The study area was Hungary, and the border was downloaded from OpenStreetMap (2023) in “shp” format. Forest mask was also used to clip satellite images aiming to keep only forest-covered pixels. The mask was downloaded from the Copernicus (2023) database at 10x10 m spatial resolution. Both datasets were uploaded into the Google Earth cloud, where the processing of remotely sensed data took place.
Sentinel-2 satellite imagery of the European Space Agency was collected in GEE to monitor the photosynthetically active period of the forest (from April until November). The satellite imagery has 10x10 m spatial and 2-5 days temporal resolution, which makes it ideal for forest monitoring. The Sentinel-2 images went through filtering and masking in GEE. Masking was made with borders of Hungary and the Copernicus forest mask, while filtering included temporal (01.04. – 31.10.) and cloud filtering with metadata property (CLOUDY_PIXEL_PERCENTAGE <= 5 %). The advantage of the Copernicus forest mask is that it is remote-sensing based, has high resolution, and is up-to-date as well. Forest ecosystem changes were monitored at annual intervals on filtered and masked vegetation index maps from 2017 until 2023. To estimate photosynthetic activity, NDVI (1) and its standardised version, Z NDVI (2), were calculated for the entire of Hungary. The NDVI (1) is calculated as (Rouse et al. 1974):

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{1}$$

where NIR is the near-infrared and RED is the surface reflectance in the red coupling channel. Forest health is evaluated on an NDVI scale from 0 to 1, where low values indicate vegetation-free ground surface or vegetation with low photosynthetic activity, while higher values indicate healthy forest vegetation with dense canopy.
However, NDVI values show a large variation over time and, in themselves, do not provide information on the extent of deviation from average conditions. Therefore, to describe the change in photosynthetic activity, the standardised version of NDVI, NDVI Z (2) was used, calculated using the formula below (Peters et al. 2002):

$$NDVI\ Z = \frac{NDVI - NDVI_{mean}}{NDVI_{std}} \tag{2}$$

where NDVI is the value measured in a given period of the year, $NDVI_{mean}$ is the multi-year average (2017-2023) corresponding to the period, and $NDVI_{std}$ is the standard deviation for the period. On the NDVI Z values, colour scale classes are indicated as follows: red refers to strong degradation where Z NDVI <-2, while orange is when Z <-1, thus still degraded. Yellow stands for slight damage or no damage (Z NDVI <0), and greens for registration: light green is where Z NDVI = 0-1 and dark green is where Z NDVI > 1), respectively.

3. Results and discussion

The Z NDVI maps were made for the forested area of Hungary between 2017 and 2023 (Figure 1, Figure 2, Figure 3). Differences were found between the seven years due to different reasons. While natural differences can be noticed due to different weather conditions each year, severe abiotic forest damage was observed as well in certain periods. In 2017 (Figure 1) and 2018, a generally positive forest health state was shown by greenish colours of the Z NDVI scale in most of the country. In 2022 (Figure 2), the Z NDVI values dropped significantly compared to these years because of the historic drought. The colours of the map are mainly yellowish-orangish and red. After the drought in 2023, a positive phenomenon was experienced, thanks to the precipitation. This year, the forest managed to regenerate, which is not yet complete. Thus, half of the map is still yellowish and only partly greenish. While mountainous areas of Hungary in the north remain reddish both in 2017, when wind and snow damage took place and in 2022 when drought caused severe problems. In 2023 (Figure 3) some mountains are still red, standing for lower vital state.

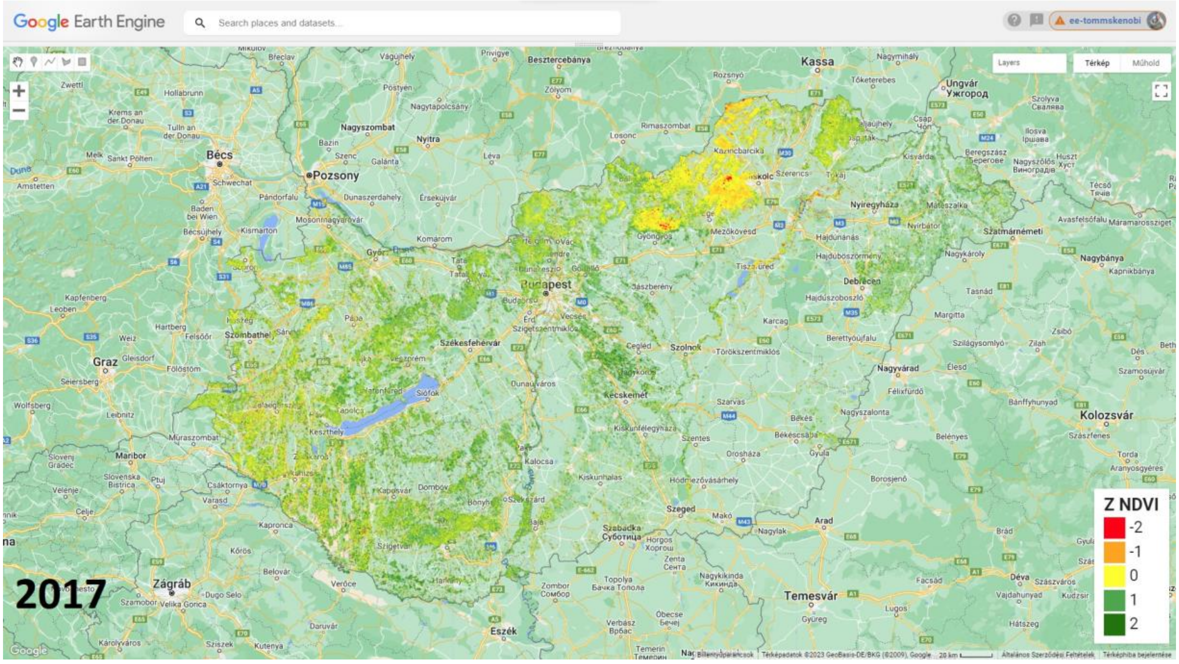

Figure 1. Sentinel-2 maps showing the health status of Hungarian forests in 2017. Generally high photosynthetic activity was detected in the majority of the country except the Northern Mountains

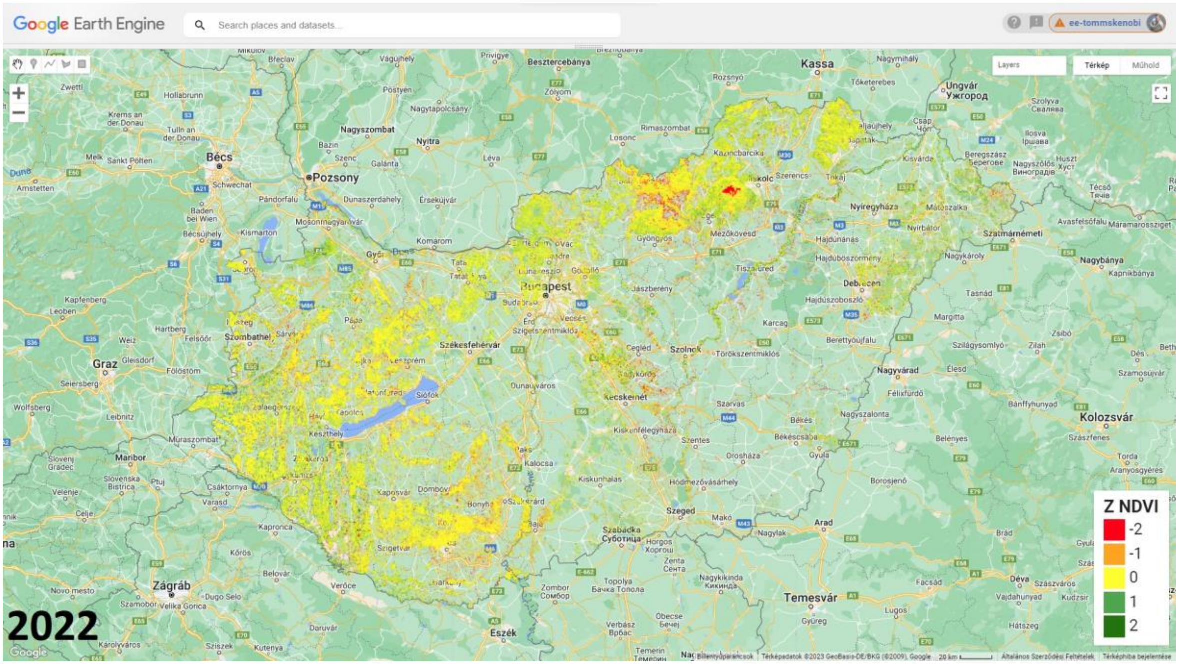

Figure 2. Sentinel-2 maps showing the health status of Hungarian forests in 2022. Due to the drought in 2022, the lowland stands' photosynthetic activity decreased significantly, which can be seen as negative index values

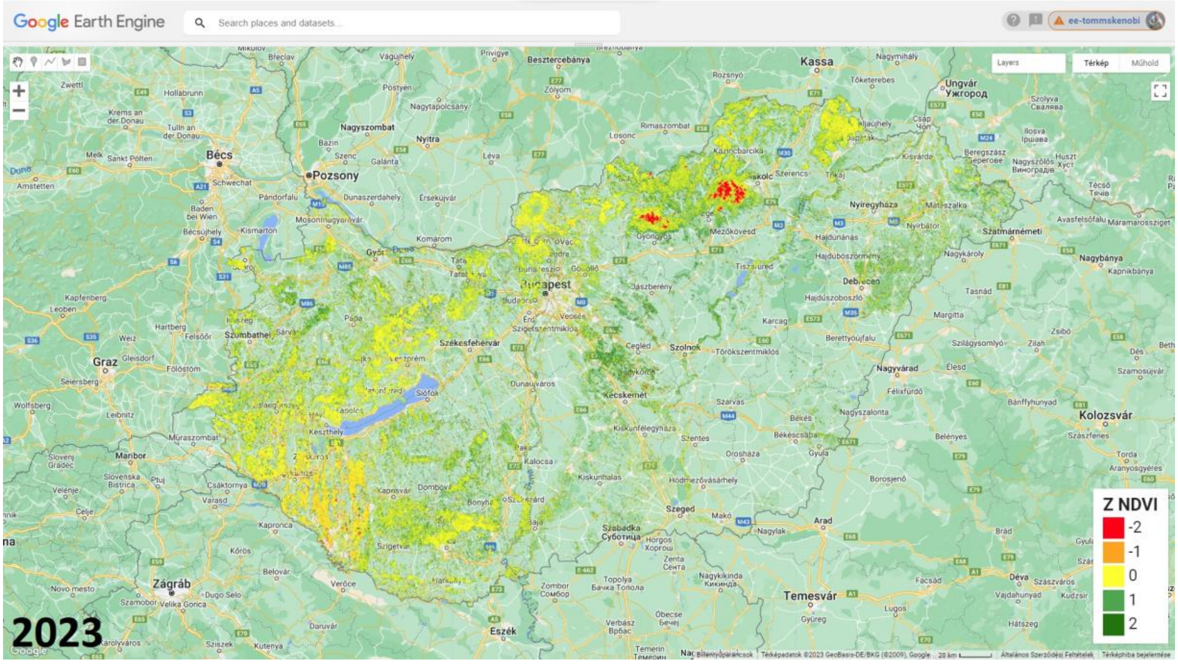

Figure 3. Sentinel-2 maps showing the health status of Hungarian forests in 2023. The regeneration in 2023 is also visible after the drought in 2022

The distribution of Z NDVI classes was analysed over the forest area of Hungary between 2020 and 2023, and significant differences were found between years (Table 1). While in 2020 and 2021, about 98 % of the forest pixels were in the neutral or positive range, in 2022, about 85 % showed negative values, including 67 % with Z NDVI values below -2, which is closely related to the historical drought. In 2023, there is an improvement, with about half of the pixels in the neutral range but the other half still in the negative range. The year 2023 was much wetter than not only the previous year but also the multi-year average, with total precipitation in most parts of the country reaching last year's annual level by August. The increased precipitation gave forests the opportunity to regenerate, which is reflected in the 2023 Z NDVI values.

Table 1: Z NDVI classes for forest area in Hungary for 2020-2023, expressed as a percentage (%)

Z NDVI class	Meaning	2017	2018	2019	2020	2021	2022	2023
<-2	severe damage	0.14	0.15	0.08	0.98	0.76	67.46	8.92
-1<	damage	0.40	1.02	0.93	1.43	1.04	17.23	42.66
0<	moderate state	3.44	70.25	38.37	36.95	28.54	15.17	48.19
1<	good	88.82	27.80	60.07	59.24	68.16	0.11	0.17
2<	excellent	7.21	0.78	0.55	1.40	1.49	0.04	0.06

The shift in the percentage classes shows the same, first deteriorating in 2020 and 2021, then improving in 2023, i.e., positive and neutral majority and negative, then neutral and negative again (Figure 4). The difference between 2021 and 2022 is the most obvious, where the NDVI class Z of 1< with 68 % was replaced by the class <-2 with almost the same percentage, 67 %. The effect of drought is therefore clearly evident, as is the improvement in 2023 due to more rain. But in 2018 there was also a drought event, which had lasting effect for the following years.

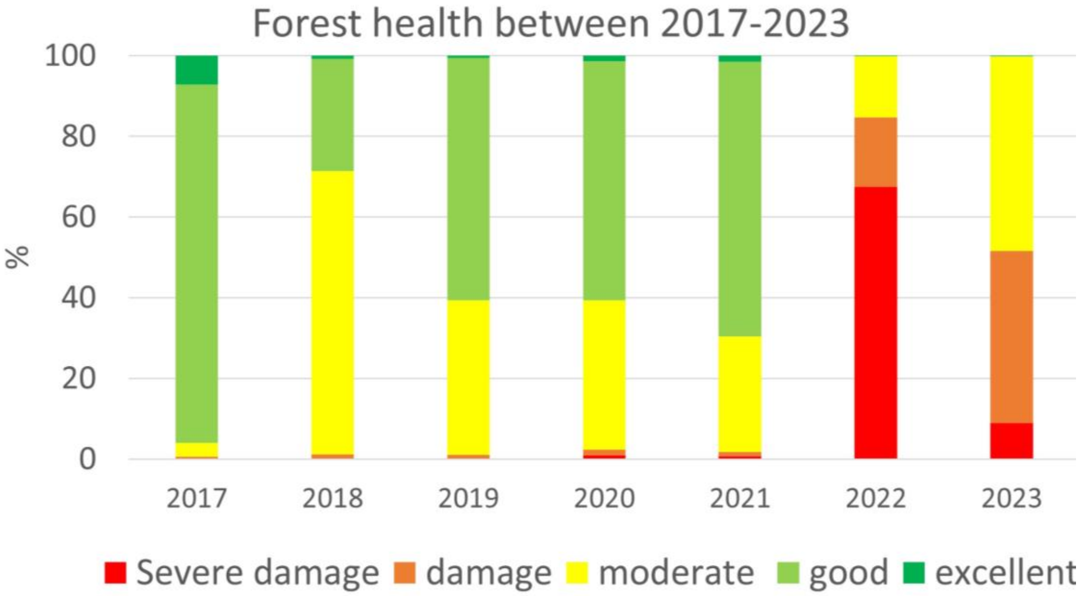

Figure 4. The NDVI classes represent the health state of Hungarian forests between 2017-2023. In 2018, the generally good health state changed compared to 2017, and this state remained for three additional years. One can also observe the very negative impact of the drought in 2022 in the severe damage category and the start of regeneration in the wetter year 2023. Despite the ongoing regeneration, it might take years to return to a normal state.

When comparing the different health categories on a spatial basis in hectares (Table 2), one can see the same proportions compared to the data expressed as percentages (Table 1). However, a significant difference can be seen in the summary row, where one can see the total number of pixels used in the year of the data. In the three years 2017-2019, 468502 pixels were used to calculate the classes at the national level, while between 2020 and 2022, this was 2263843, a difference of almost five times, which is a very significant improvement towards reliability. In 2023, only the data for the first eight months were available at the time of writing the article, but even so, 857868 pixels were available, almost double the pixels of the first three years. The difference is due to cloud coverage, which varies every year, and it has an impact on data quality, too, since cloud-covered and cloud-saturated pixels are also filtered, which decreases the number of used pixels in the analysis.

Table 2: Z NDVI classes for forest area in Hungary for 2020-2023, expressed in hectares (ha)

Z NDVI class	2017	2018	2019	2020	2021	2022	2023
<-2	639	712.4	377.25	22,241.76	17,150.68	1,789,753.33	76,488.66
-1	1,878.39	4,761.07	4,344.03	32,321.97	23,621.94	457,176.27	365,961.81
0	16,094.9	329,144.78	179,779.61	836,392.6	646,192.19	402,426.09	413,427.42
1	416,126.62	130,235.75	281,407.64	134,1171.16	1,543,037.19	2,808.15	1,460.2
2<	33,763.22	3,648.13	2,593.6	31,715.59	33,840.99	1,048.76	529.52
Total	468,502.13	468,502.13	468,502.13	2,263,843.08	2,263,842.99	2,653,212.6	857,867.61

4. Conclusions

The application of Sentinel-2 satellite imagery in Google Earth Engine proved to be an effective tool for forest monitoring purposes in Hungary. For the seven-year-long period (2017-2023), the annual changes were visible and corresponded to the extreme weather experiences. The vegetation index values were able to capture both the negative and positive forest health changes. Classification of Z NDVI pixels into classes also proved useful for showing deviations from healthy, normal states. In 2022, due to the large-scale drought, the Z NDVI values dropped significantly compared to previous years, while in 2023 regeneration was experienced thanks to the precipitation, however, regeneration is not complete. The monitoring shall be continued, and yet longer image series is desired to enhance monitoring precision, namely the mean and standard deviation values will be more reliable in time. In parallel with the prolonged time series, more pixels would also be needed to create completely cloud-free satellite composites, which is very challenging due to cloud cover issues. However, a perfect method for that does not yet exist, which is problematic, especially when one would desire to create monthly composites instead of annual ones, which can capture better phenological changes in forests. This monitoring system can inform forestry companies about the quality of their forests, and forest conservation and management strategies can be planned based on this remotely sensed information, which endorses nature conservation and sustainable management as well. The impact of climate change can also be surveyed through analysis of time series of satellite imagery. For that implication, longer (20-30 y long) time series are recommended since the analysis of shorter periods could be problematical due to data gaps, which could occur due to cloud coverage or other technical errors. However, gaps can be filled with the combination of different satellite imagery, like Sentinels with Landsat called Harmonized Landsat and Sentinel-2 (HLS). On the other hand, the GEE system has limitations. Thus, extremely long time series for large areas cannot be analysed in the cloud, but as the results showed, even country-wide maps can be created, which is promising for future applications.

Acknowledgements

This article was made in the frame of the project TKP2021-NKTA-43, which has been implemented with the support provided by the Ministry of Culture and Innovation of Hungary from the National Research, Development and Innovation Fund, financed under the TKP2021-NKTA funding scheme.

References

Copernicus, 2023, Tree Cover Density 2018. <https://land.copernicus.eu/pan-european/high-resolution-layers/forests/tree-cover-density/status-maps/tree-cover-density-2018>, accessed 24.07.2023.

ESA, 2023, SENTINEL-2 mission guide. European Space Agency, <https://sentinel.esa.int/web/sentinel/missions/sentinel-2>, accessed 24.07.2023.

FAO, 2023, Sustainable forest management. Food and Agriculture Organization, <https://www.fao.org/sustainable-forests-management/en/#:~:text=The%20aim%20of%20sustainable%20forest,the%20sustainable%20development%20of%20communities.>, accessed 24.07.2023.

Franklin S.E., 2001, Remote Sensing for Sustainable Forest Management. CRC Press, Florida, USA, 124.

Gorelick N., Hancher M., Dixon M., Ilyushchenko S., Thau D., Moore R., 2017, Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote Sensing of Environment, 202,18-27.

Hanpattanakit P., Kongsaenkaew P., Pocksorn A., Thanajaruwittayakorn W., Detchairit W., Limsakul A., 2022, Estimating Carbon Stock in Biomass and Soil of Young Eco-Forest in Urban City, Thailand. Chemical Engineering Transactions, 97, 427-432.

Hossain K.A., Masiero M., Pirotti F., 2022, Land cover change across 45 years in the world's largest mangrove forest (Sundarbans): the contribution of remote sensing in forest monitoring. European Journal of Remote Sensing, 11(2), 259-277.

Khruschev S.S., Plyusnina T.Y., Antal T.K., Pogosyan S.I., Riznichenko G.Y., Rubin A.B., 2022, Machine learning methods for assessing photosynthetic activity: environmental monitoring applications. Biophysical Reviews, 14(4), 821-842.

Nandasena W.D.K.V., Brabyn L., Serrao-Neumann S., 2022, Using Remote Sensing for Sustainable Forest Management in Developing Countries. In: The Palgrave Handbook of Global Sustainability. Palgrave Macmillan Cham, London, UK, 22.

OpenStreetMap, 2023, Administrative borders. (in Hungarian), <https://data2.openstreetmap.hu/hatarok/index.php?admin=6>, accessed 24.07.2023.

Peters A.J., Walter-Shea E.A., Andrés Viña L.J., Hayes M., Svoboda M.D., 2002, Drought monitoring with NDVI-based standardized vegetation index, Photogrammetric Engineering and Remote Sensing, 68(1),72-75.

Rouse J.W., Haas R.H., Scheel J.A., Deering D.W.,1974, Monitoring Vegetation Systems in the Great Plains with ERTS, Proceedings, NASA Spec. Publ, 1974, 351(1): 309-313.

Vyvlečka P., Pechanec V., 2023, Optical Remote Sensing in Provisioning of Ecosystem-Functions Analysis—Review. Sensors, 23(10), 493.