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AN ANALYSIS OF THE EVAPOTRANSPIRATION IN THE ARGES RIVER BASIN USING MODIS MOD16A2

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Abstract

This work presents an analysis of the evapotranspiration in the Arges River Basin, including a riparian system located near Dragomiresti village, using MODIS Global Terrestrial Evapotranspiration 8-Day Global (MOD16A2) at 500-m pixel resolution to assess the amount of water lost from the hydrologic budget. The period of coverage is 8 days during the vegetation season of the considered period (2015-2022). The geospatial analysis of the selected riparian systems was performed with ArcGIS Desktop 10.8.1 and Google Earth Engine. Arges River supplies water for several important Romanian cities, and thus, the rationale of this work relies on the characterization of evapotranspiration for potential better management. Riparian vegetation has multiple functions and provides a wide range of ecosystem services of which yields are directly influenced by the river basin`s ecological status. Limiting anthropogenic disturbance is important for the health of lotic ecosystems. The utilization of MODIS does not provide fine-scale resolution (< 10 m), making it difficult to discriminate between phytosociological associations at a small scale and thus establish the riparian systems' typology and associated vegetation indicators. Downscaling and data fusion methods will be further explored.

Key words: *MODIS, MOD16A2, riparian grasslands, riparian systems, geospatial analysis, ecological efficiency, Google Earth Engine.*

INTRODUCTION

Performing multidisciplinary research on the dynamics of herbaceous mixed canopy growth and development (Constantinescu et al., 2019), and the multifunctional potential of grasslands located in riparian areas is required because of the agri-environmental implications and benefits of these zones (Dunea et al., 2019). Riparian vegetation is a central component of the hydrosystem (Huylenbroeck et al., 2020) providing a series of important ecosystem services such as:

- Water quality regulation and site-specific pollution mitigation (up-take of heavy metals and retention/recycling of nutrients) (Stutter et al., 2021; Dunea et al., 2020);
- Biodiversity conservation (wildlife protection near neighboring farmlands or urban areas by provisioning food and habitat);
- Goods and habitat provisioning (Source of raw materials; corridor function - enhances the movement of organisms);
- Discharge control and flooding avoidance (influence on kinetic energy and turbulence, and diminishing of the velocity of runoff reaching the riverbed) (Dingman, 2014; Sabău et al., 2023);
- Climate regulation (decrease of in-stream and local temperatures; the presence of trees modifies wind currents) (Abatzoglou et al., 2018);
- Disturbance prevention (maintenance of riverbank stability and protection from erosion) (Dingman, 2014);
- Carbon storage (restoring and reforesting of riparian zones along headwater streams would both increase carbon storage and improve water quality) (Rheinhardt et al., 2012);
- Noise dissipation from nearby traffic;
- Aesthetic and recreational use.

Farming to maximize economic performance is usually in conflict with wildlife needs (Whittingham, 2007). Most of the time, the farmlands are areas located near riparian areas, making them important shelters for wildlife. The grasslands are usually grazed by the livestock from the neighboring villages because of their good pastoral value and enhanced floristic composition (Dunea et al., 2021a).

Establishing the relationship between the environmental factors and the dynamics of the growth and development of the canopy specific to the grasslands located in riparian areas requires more attention to the study of the availability of solar radiation resources, the seasonal fluctuations and distribution of leaf area, the evapotranspiration, and other biological factors, and the efficiency of estimation methods based on the remote sensing products and modern data processing tools (GIS software) and platforms e.g., Google Earth Engine - GEE (Dunea et al., 2021b).

One of the objectives is to highlight the efficiency and usefulness of remote sensing methods with the help of sensors equipped on vegetation monitoring satellites launched into the Earth's orbit (McShane et al., 2017).

The extraction of vegetation indices consists of establishing how the radiative properties of interest of a variable - characteristic of an entity at the level of the terrestrial surface affect the spectral reflectance to be captured and the interpreted results.

Generally, there is a good correlation between the synthetic vegetation indices and different parameters specific to the growth and development of the canopy, such as reliable yield, leaf surface, photosynthetic activity, density, and distribution of component species (Dunea & Dincă, 2014).

The increase in vegetation cover, respectively the weight of vegetation at the level of a grassland system, leads to an increase in reflectance in the near-infrared channel and a decrease in reflectance in the red channel of the visible spectrum; in this case, the reflectance values in IRa are higher than those in red, which indicates a grassland with an integral soil cover, and an increase in the biomass, without external stress factors.

Consequently, the specific objectives of the research are related to the study of dynamics of the growth and development of the herbaceous canopy of the riparian grasslands including the floristic composition and the eco-pedoclimatic conditions with an accent on availability of the solar resources. Secondly, the evaluation and improvement of the multifunctional potential of the riparian grasslands are also envisaged.

In this paper, the evapotranspiration in the Arges River Basin (R.B.), including a riparian system located near Dragomiresti village, was analyzed between 2015 and 2022 using the GEE environment for MODIS Global Terrestrial Evapotranspiration 8-Day Global (MOD16A2) at 500-m pixel resolution to assess the amount of water lost from the hydrologic budget. Other available resources from MODIS related to the Leaf Area Index (LAI), the Normalized Difference Vegetation Index (NDVI), and the Enhanced Vegetation Index (EVI) were also considered and discussed.

MATERIALS AND METHODS

Study area

Arges River is a left tributary of the Danube River with a length of 350 km and a basin area of approximately 12,550 km^2, representing 5.3% of Romania's total area (Figure 1).

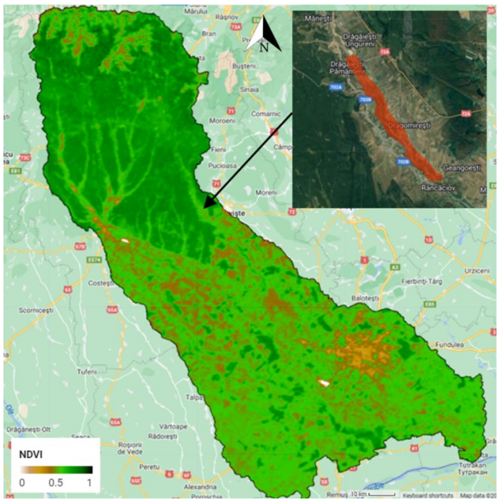


Figure 1. Arges River Basin showing an NDVI example (May-July 2022) using the 'MODIS/MCD43A4_006_NDVI' Image Collection, and the riparian system selected as a case study for evapotranspiration near Dragomiresti village on Dambovita River (processed with Google Earth Engine)

Identification and evaluation of the significant environmental impacts on the watercourses and adjacent riparian areas in the hydrographic basin of the Arges River are required either from discharges of treated or untreated waters in

surface waters (from sources of urban pollution/human settlements and/or industrial sources), or diffuse pollution, from agriculture and other sources.
The source is located in the Fagaras Mountains, and it flows into the Danube River at Oltenita. The capital Bucharest and other important cities (Pitesti, Curtea de Arges, Campulung, Gaesti, Oltenita) are supplied with water from the Arges R.B. Arges River gathers 178 codified watercourses with a length of 4579 km (5.8% of the total length of codified watercourses in Romania). The density of watercourses is 0.36 km/km^2.
Regarding the land cover, the non-irrigated arable land reaches 46% (Corine Land Cover - CLC category 211), forests 26.2% (5.2% of the national forest fund), watercourses (CLC 511) 12%, and the discontinuous urban fabric (CLC 112) 4%, respectively (Dunea, 2022). Based on these indicators, the Arges R.B. is important for agriculture and has key forest resources (approximately 3283 km^2).
The water quality of Arges River is affected by industrial and agricultural activities with point and nonpoint source pollution, including toxic contaminants (dissolved Ni, Cr, and Pb), and nutrients, which can degrade water quality, especially in the lower part of the river (Dunea, 2022).

Data processing and statistics
was performed using mainly the Google Earth Engine (GEE) platform. GEE is a catalog of satellite imagery and geospatial datasets with planetary-scale analysis capabilities for detecting changes, mapping trends, and quantifying differences on the Earth's surface. GEE is free for academic and research use. In this environment, we used specific scripts in Python for accessing and collecting the required data for the Arges R.B. between the considered periods (2015-2022) and for drawing specific maps.
We imported the basin limits and river network as layers retrieved with ArcGIS 10.8.1 and imported them in GEE as an 'asset'. The retrieved time series were analyzed using the SPSS software (SPSS Inc., Chicago, IL, USA, 2011). The variability was determined using descriptive statistics (average, coefficient of variation, skewness, kurtosis, etc.). Because this is a preliminary screening study regarding the variability of the considered parameters within the basin, detailed time series analysis and complex statistics were not employed at this stage.

Vegetation indices and corresponding collections
Leaf area index (***LAI***) is the unitless ratio of green leaf area to ground area (m^{-2} m^2). We used the LAI derived from the MCD15A3H.006 MODIS data product (Myneni et al., 2015). This algorithm derives 4-day composite LAI values at a 500 m spatial resolution from the Terra and Aqua satellites and is available from 2003 onwards.
Within this 4-day period, the most accurate pixel is selected from the MODIS sensors located on the Terra and Aqua satellite for the calculation of the LAI. The LAI calculation algorithm uses a lookup table that was generated using a 3-D radiative transfer equation (Myneni et al., 2015). MODIS LAI has a long record length, reliable and free data availability, proper spatial coverage, and adequate temporal resolution.

Enhanced Vegetation Index (EVI) and NDVI
EVI is an advanced vegetation index with higher sensitivity to biomass, atmospheric background, and soil condition. We used the MOD13A1 V6.1 product, which provides a Vegetation Index (VI) value per pixel basis. There are two primary vegetation layers.
The first one is the NDVI, which is referred to as the continuity index to the existing National Oceanic and Atmospheric Administration-Advanced Very High-Resolution Radiometer (NOAA-AVHRR) derived NDVI.
EVI is the second one and minimizes the canopy background variations and maintains sensitivity over dense vegetation conditions. The EVI also uses the blue band to remove residual atmosphere contamination caused by smoke and sub-pixel thin cloud.
The MODIS NDVI and EVI products are computed from atmospherically corrected bi-directional surface reflectance that have been masked for water, clouds, heavy aerosols, and cloud shadows. (https://doi.org/10.5067/MODIS/MOD13A1.061).

Evapotranspiration

We used the MOD16A2 Version 6 Evapotranspiration/Latent Heat Flux product, which is an 8-day composite product at 500-meter pixel resolution.

The algorithm used for the MOD16 data product collection is based on the Penman-Monteith algorithm, which includes inputs of daily meteorological reanalysis data along with MODIS remotely sensed data products (vegetation property dynamics, albedo, and land cover).

The pixel values for the two Evapotranspiration layers (ET & PET) are the sum of all eight days within the composite period (Mu et al., 2011). The pixel values for the two Latent Heat layers (LE & PLE) are the average of all eight days within the composite period (https://doi.org/10.5067/MODIS/MOD16A2.006).

RESULTS AND DISCUSSIONS

The applied tests aimed to develop a procedure that can ensure the detection of changes in vegetation and ET characteristics concerning phenology and seasonal variations in the growing season at the river basin level and a riparian system from the basin.

Moreover, the detection of changes is an important step for scaling procedures, which will be developed, if possible, by inferring high-resolution information from low-resolution variables to increase the spatial resolution of ET estimates (Singh et al., 2014).

The first step in ET calculation involves partitioning incident solar radiation into net radiation available to plants and soil. This is done by calculating the vegetation condition using the LAI parameter.

Figure 2 presents the LAI distribution at maximum development in June at the basin level and selected riparian system, and the evolution between 2015 and 2022 as a mean calculated for the river basin.

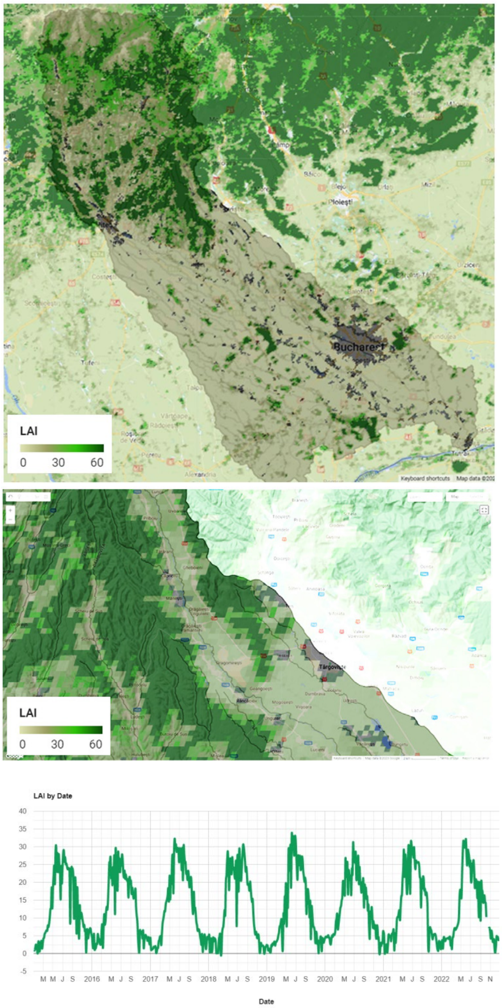


Figure 2. Leaf area index (LAI) retrieved using MCD15A3H.006 MODIS data product (Valid Range = 0-100; Scale Factor = 0.1) at basin scale, at riparian area scale, and the time series from 2015 to2022 (http://doi.org/10.5067/MODIS/MCD15A3H.006)

It can be noted that the highest LAI is usually reached in June with a maximum in the year 2019 and minimum values in 2015 and 2016 (2015 was one of the driest years in the last 50 years). EVI and NDVI are other important indices that characterize the status of vegetation (Figures 3 and 4).

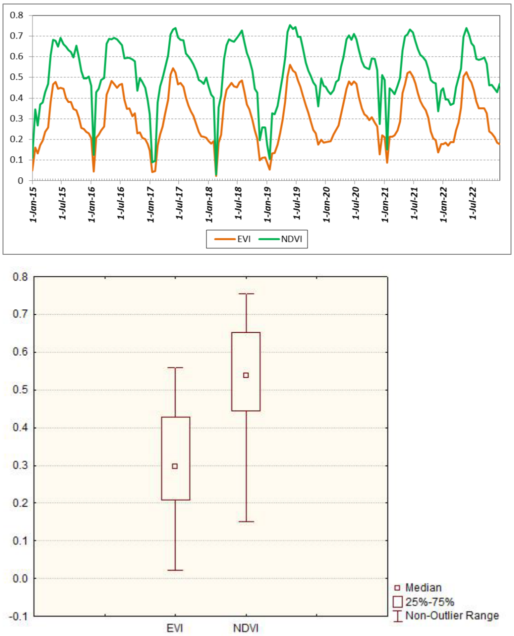


Figure 3. Average EVI and NDVI time series from January 1, 2015, to December 31, 2022, using MOD13A1.061 Terra Vegetation Indices 16-Day Global 500-m Collection for the Arges R.B. (minor ticks = 16 days); Median and percentiles of the period (box-whisker graph)

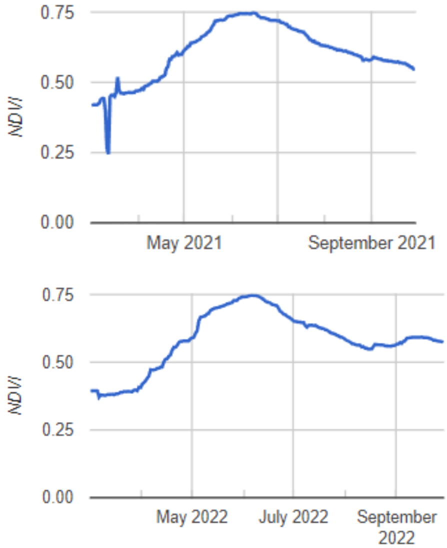


Figure 4. NDVI retrieved for the vegetation seasons of years 2021 and 2022 based on the 'MODIS/MCD43A4_006_NDVI' Collection

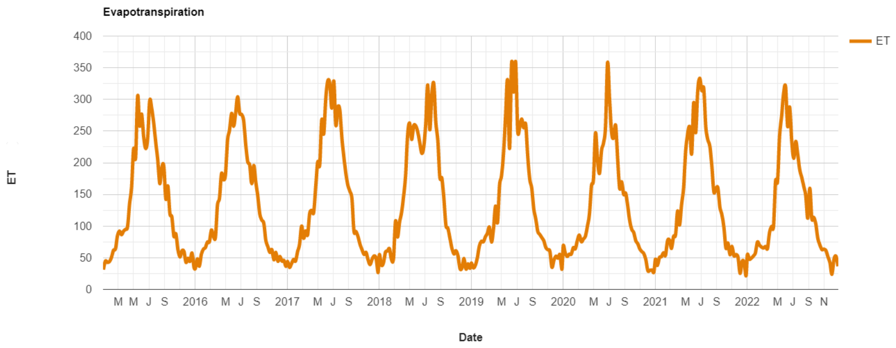
Table 1 presents the descriptive statistics of the analyzed time series i.e. EVI, NDVI, ET, and PET for the whole basin, and cumulative PET for the riparian system located near Dragomiresti village.

Table 1. Descriptive statistics of the time series retrieved from the MODIS Datasets (2015-2022 excepting PET for the riparian system - PET_RP for which the period is 2015-2019*); ET and PET - kg/m^2/8-day

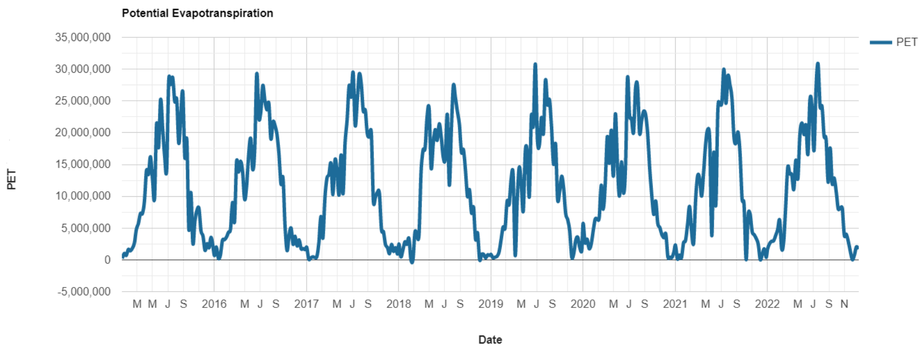
Indicator	Valid N	Time step	Mean	Median	Minimum	Maximum	Range	Quartile	Std.Dev.	Coef. Of Var.	Skewness	Kurtosis
EVI	184	16-Day	0.31	0.30	0.02	0.56	0.54	0.22	0.13	41.97	0.04	-0.97
NDVI	184	16-Day	0.53	0.54	0.03	0.75	0.72	0.21	0.15	28.43	-0.88	0.81
LAI	729	4-Day	1.30	1.07	0.00	3.33	3.33	1.72	0.96	73.72	0.35	-1.30
ET_ARB	367	8-Day	134.76	98.92	21.62	358.85	337.23	151.65	89.70	66.57	0.69	-0.83
PET_ARB	367	8-Day	11,398,935.22	10,035,953.71	5113	30,846,772.80	30,841,659.80	15,873,096.27	8,795,739.38	77.16	0.38	-1.12
PET_Rp*	230	8-Day	2003.22	1362.45	0.00	7019.25	7019.25	2657.09	1786.52	89.18	0.84	-0.49

At the river basin level, based on the statistical indicators of the time series from 2015 to 2022, EVI showed a mean of 0.31 with a maximum of 0.56 and a C.V. (coefficient of variation) = 41.97%. NDVI had a mean of 0.53 ranging between 0.03 and 0.75 and a C.V. = 28.43%, which was the lowest value from all the tested parameters. This suggests the constancy of the vegetation in the basin. The LAI reached a maximum of 3.33 with a mean of 1.3 and a C.V. = 73.72%. This denotes a higher variance of the LAI due to the influence of water availability. Cumulative PET showed a similar C.V. value (77.16%) and mean ET had also a high C.V. (66.57%) at the basin level. From 2015 to 2022, ET recorded a mean of 134.76 kg/m^2/8-day, a minimum of 21.62, and a maximum of 358.85 kg/m^2/8-day.

Figures 5 and 6 provide clear insights into the ET and PET variability at the basin level showing the lowest values in years 2015 and 2016, and the highest in 2019 and 2020.



a)



b)

c)

Figure 5. Evapotranspiration indices (kg/m[2]/8-day) retrieved using MOD16A2.006: Terra Net Evapotranspiration 8-Day Global 500m (https://doi.org/10.5067/MODIS/MOD16A2.006) between 2015 and 2022: a) Actual evapotranspiration - averaged at Arges River basin level; b) potential evapotranspiration - cumulative values at basin scale; c) potential evapotranspiration - cumulative values at Dragomirești riparian system level (2015-2019 period selected)

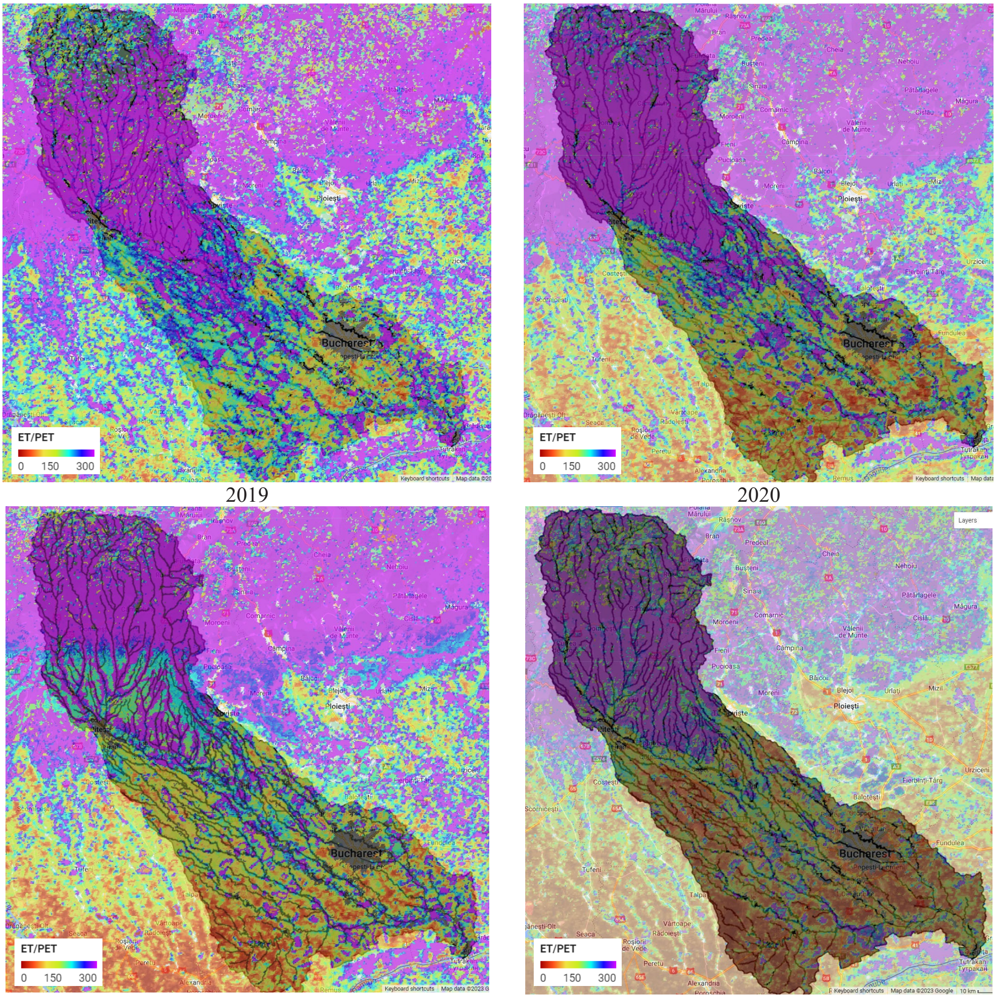


Figure 6. Maps of potential evapotranspiration - means (kg/m^2/8-day) obtained using MOD16A2.006: Terra Net Evapotranspiration 8-Day Global 500-m (https://doi.org/10.5067/MODIS/MOD16A2.006)

The potential ground-level evaporation is calculated using the Penman-Monteith algorithm based on meteorological parameters and vegetation characteristics (e.g. height, conductance factor, maximum leaf conductance, albedo, LAI). Based on the cumulative PET, the lowest values were in the year 2018, and the highest in 2019 and 2022. Regarding the riparian system, the cumulative PET was relatively constant between 2015 and 2019.

This may be related to the capacity of riparian systems to maintain a balanced hydrological feature (https://directives.sc.egov.usda.gov/18532.wba).

The Arges River from Romania and its tributaries encounter significant pressures from anthropogenic factors passing highly inhabited areas with moderate efficiency of wastewater treatment. In addition to the potentially significant pressures already presented above, other types of activities/pressures may affect the condition of water bodies such as accidental pollution, fishing, and aquaculture activities, ballast and sand extraction from minor riverbeds, forest exploitation, unidentified pressures, etc. Riparian buffer zones may diminish the negative effect, but this requires proper management. Grasslands from these areas are also of interest and the current study gives good promises for using remote sensing in determining long-time processes that affect the floristic composition.

CONCLUSIONS

Observation of evapotranspiration (ET) processes using the existing remote sensing systems is a key element that provides up-to-date information for water resource management, weather forecasting, climate studies, agriculture, and other essential applications. Easy access to reliable ET estimates is important in these strategic areas. When ET values are successfully estimated at high resolutions, water scarcity at land surfaces can be mapped and hot spots can be better investigated. At this point, the analyzed datasets provided a good assessment of the processes related to vegetation evolution, pointing out the reductions during the drought periods. Further work will consider the utilization of downscaling and data fusion methods in combination with other high-resolution products for application in monitoring the grasslands located in the riparian systems.

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