Time series satellite data for assessment of drought impacts on vegetation land cover in dryland Constanta County, Romania

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ABSTRACT

In the frame of the global warming context arid regions are affected by increases in temperature and decreases in precipitation, which will trigger water shortages, drought, and further aridification. This paper addresses several issues related to current and future climatic change and drought impacts on vegetation land cover, focusing on Constanta County in Dobrogea region placed in the southeastern part of Romania near the North Western Black Sea coastal area. Remotely sensed monitoring and assessing of drought effects in long-term change could provide sound understanding to guide arid agricultural areas' ecological restoration and local ecosystem sustainability. This study examined the applicability of MODIS Terra/Aqua time series satellite-based together MERRA -2 reanalysis data in synergy with in-situ monitoring of climate observables for aridity assessment. Time series of Normalized Difference Vegetation Index - NDVI, evapotranspiration-ET, land surface albedo-LSA, land surface temperature-LST, and air surface temperature-AT at different time scales and other climate parameters (precipitation rate, relative humidity, and surface solar irradiance-SI were computed for the period 2002 to 2023. The trend analysis of the time series for ET, NDVI, and LST in the Constanta Cunty was conducted using a simple linear regression analysis method. During the summer periods (June – August) of the 2021-2023 period, LST and NDVI appeared to be linear and negatively correlated in each year ranging from $r = -0.85$ with $p<0.05$ in the 2022 year, $r = -0.77$ with $p<0.05$ in the 2021 year, and $r = -0.40$ with $p<0.05$ in the 2023 year. A high decrease of NDVI values ranged (0.2-0.3) was recorded during summer-autumn drought periods of years 2022 and 2023 associated with strong heat waves. The results of this study show that a large area of Constanta County is highly controlled by drought during the summer to autumn seasons. This work demonstrates the importance of satellite remote sensing data conjugated with in-situ data for changes monitoring of dryland vegetation in their response to climate-drying conditions.

Keywords: Drought, land surface albedo, land surface temperature, biophysical parameters, time series MODIS Terra/Aqua satellite data, Constanta County, Romania.

1. INTRODUCTION

Due to human-induced climate change, and global temperature rise due to the accumulation of anthropogenic greenhouse gases in the atmosphere, during the last few years, drought and heat extreme events are becoming more frequent and long-lasting, especially in the Central and Southern part of Europe affecting ecosystem functioning with devastating ecological and socio-economic impacts. Also, the intensity of these extreme drought and heat events is not spatially and temporally uniform. Understanding the spatial variability of drought impacts is important information for decision-makers, supporting both planning and preparations to cope with the changing climatic conditions in Europe[1,2]. Drought represents one of the most prominent environmental threats, which disrupts the hydrological balance of the land cover and impairs its agricultural productive capacity, posing risks to the environment, natural ecosystems, and human civilization. Being a complex phenomenon is characterized by the decrease in soil moisture to a level that affects natural vegetation and crops at different stages of crop development. Drought is a long-term average condition of the precipitation-evapotranspiration balance at a specific location, that exhibits distinct climatic features associated with the decreasing rate of precipitations and increasing air and land surface temperature, and consequences due to the intricate relationship between dryness, the timing, and the intensity of rainfall [3,4].

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Scientific studies reported consecutive multi-year meteorological summer droughts, such as those of 2018 to 2022 in Central, Eastern, and Western Europe [5], attributed to lower-than-normal precipitation and higher-than-normal evaporative demand, which resulted in a greater reduction of soil moisture content in the second year of the drought, with potentially more extreme drought impacts [6]. Some studies found a significant increase in drought frequency during spring and summer seasons in the Southern and Western parts of Europe, and a decrease in autumn and winter seasons in Northern and Eastern parts of Europe [7]. At the regional level, the Southern and Eastern parts of Romania are under the pressure of
increasing drought conditions, where due to especially the summer highest temperatures are recorded the most frequent severe and moderate drought events (the Dobrogea Plateau, the Danube Delta, and the Romanian Plain). However, these regions experienced the lowest amounts of precipitation, while the highest amounts of precipitation were recorded in the Carpathian Mountainous areas. Extreme heat events recorded in 2003, 2007, 2009, 2011, 2018, 2019, 2020, 2022, and 2023 were associated with extreme droughts that affected all agricultural areas. Heat waves and droughts fall into the category of climate-related hazards which more and more frequently affect socio-economic activity, often having serious repercussions on humans and the environment [8].
As droughts stand among the most damaging natural disasters, which threaten agricultural production, ecological environment, and socio-economic development, drought monitoring and early warning, accurate evaluation, and efficient prediction are emergency issues. In regional-scale research, remote sensing techniques provide significant spatial and temporal data for finding environmental changes that occur over time. Many researchers across the world use remote sensing data to estimate surface temperature and surface emissivity. Precision farming in agricultural applications has become more dependent on thermal remote sensing technology to identify water-stressed crops, plant diseases, and irrigation management [9]. Time series satellite data are very useful for spatiotemporal variations of drought and soil characteristics changes [10, 11]. Among drought consequences with negative impacts on soil properties are: a reduction in organic matter and nutrients, diminished nutrient transport, increased permeability, heightened wind and water erosion, destruction of its texture and structure, increased evaporation from surfaces, and an overall decline in soil quality [12]. Visible (VIS), infrared (IR), and other electromagnetic wavelengths of spectrum-based remote sensing are used for monitoring of different Earth's surface features (soil, vegetation, water, biomass) and other land surface variables. Both active and passive remote sensing sensors are used for monitoring soil moisture, which is a crucial variable for governing agricultural, hydrologic, and land-atmosphere-interaction processes [13].
In the frame of ongoing climate change, the analysis of heat waves and droughts extreme events, in terms of changes in their frequency and magnitude as well as the analysis of the large atmospheric circulation patterns that favor their occurrence, is of increasing scientific interest.
This paper is focused on the current and future climatic changes and drought impacts assessment on vegetation land cover in the Constanta County in Dobrogea region placed in the southeastern part of Romania near the North Western Black Sea coastal area. MODIS spectral reflectance and land surface temperature products were used to obtain temperature, moisture, and greenness-based indicators. This study applied time series MODIS Terra/Aqua satellite data together with MERRA -2 reanalysis climate data in synergy with in-situ monitoring of climate observables for drought conditions assessment. Derived satellite data for Normalized Difference Vegetation Index (NDVI), leaf area index-LAI, evapotranspiration-ET, land surface albedo-LSA, land surface temperature-LST, as well as air surface temperature-AT at different time scales and other climate parameters (precipitation rate, relative humidity, and surface solar irradiance) have been used for 2002 to 2023 time period. Greenness anomaly indicators and land surface temperature indicators have been used to assess vegetation drought stress.

2. STUDY TEST AREA

The study test area, Constanta County belongs to the Dobrogea region and is located in the South-Eastern part of Romania, being surrounded to the North by Tulcea county, to the East by the Black Sea, to the South by Bulgaria, and to the West by the Danube, which forms a natural border with the Calarasi and Ialomita counties. The county's capital city is Constanta. Being located in the Dobrogea Plateau, it has a predominantly low-elevation plateau structure. The climate is temperate-continental with strong continental influences, an average annual temperature of 10-11°C, and rainfalls less than 450 mm/year, under the national average, being affected by drought events and degraded soils which cause significant damages and economic costs over extensive agricultural areas. Risk reduction, continuous vegetation monitoring, and management implementation are facilitated by the complementary use of vegetation indices and biophysical parameters derived from satellite products (gridded data) and within-situ data (point data). The Black Sea

influences the climate over tens of kilometers inside the county. The soil mainly consists of chernozems characteristic of the Dobrogea steppe (carbonate chernozem, brown chernozem, chocolate chernozem, and levigate chernozem). The County's subsoil contains rocks including phosphate, green schists, lime, chalk, argil, dolomite, diatomite, melting sand, iron ore, and mineral waters. Due to the climate change variability and the increased frequency of extreme events, during recent years in Dobrogea has been recorded a decreasing trend of agricultural production from one year to another. Dobrogea region has a high level of drought risk as in this part of Romania, the annual average temperature is over 11 ºC and the rainfalls vary between 351 and 450 mm/year on average. As the test area was selected Cuza Voda centered on Latitude 44.284589 ºN and Longitude 28.322583ºE, and the surface of 40.5 km x 40,5 km, placed in the Constanta County in Dobrogea region in the Southern-Eastern part of Romania (Figure 1).

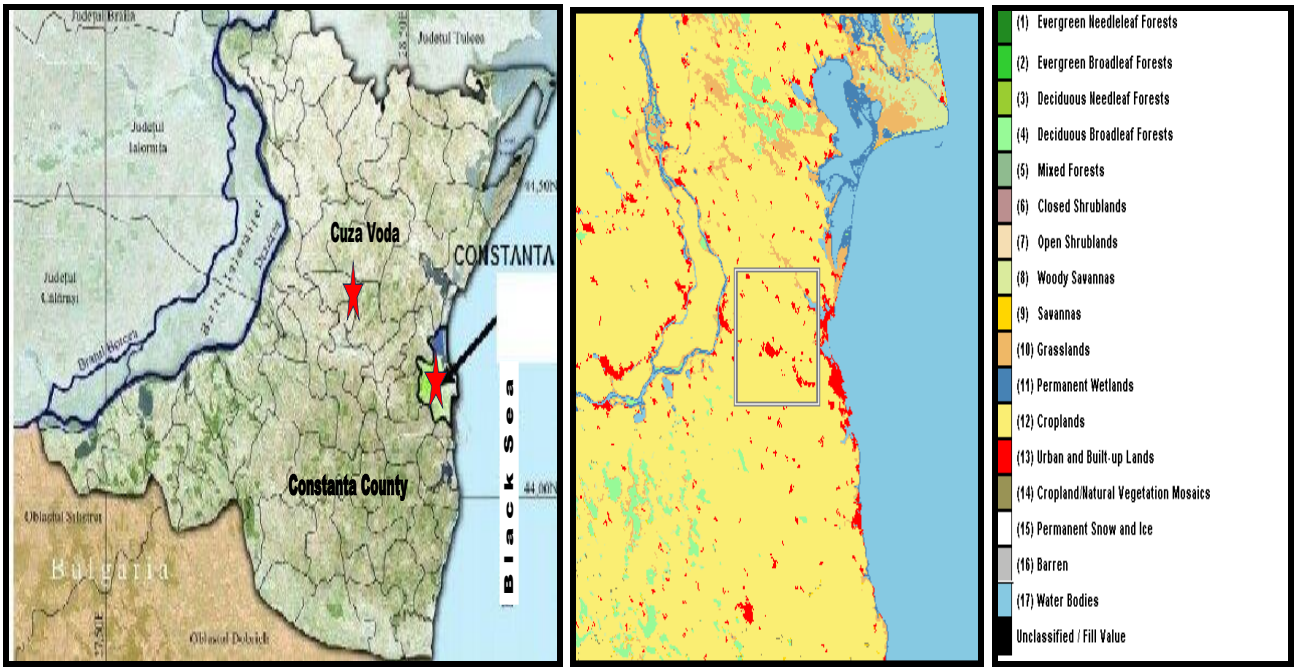

Figure 1. Location of test area Cuza Voda in Constanta County, and Dobrogea region in Romania

3. METHODS AND DATA USED

The time series analysis of derived biogeophysical parameters for the Cuza Voda area located in Constanta County is based on the time series MODIS Terra/Aqua acquired during the 2002-2023 period. During the analyzed period have been registered several heat waves periods, of which summer 2003, 2007 and 2010, 2012, 2017, 2022, and 2023 have been the highest. We used time series MODIS Terra products: 8-Day L3 Global 1km SIN Grid land surface temperature (LST)/emissivity MOD11A2/LST_Day_1km, 16-day MODIS 13Q1/250m_16_days_NDVI/EVI composites with a 250 m spatial resolution, MCD43A/VIS and NIR surface albedo, mainly for their capacity to detect anthropogenic and climate impacts on soil surface and land cover changes. Also, the actual evapotranspiration (ET) evapotranspiration (PET) data were from the MOD16A2 8-Day at 500 m dataset within the Earth Observing System (EOS)/MODIS data products provided by the National Aeronautics and Space Administration (NASA) (https://ladsweb.modaps.eosdis.nasa.gov). These data are 8-day composite products with a resolution of 500m × 500 m. Missing values were replaced by linear interpolation considering neighboring values within the LST, NDVI/EVI, and evapotranspiration-ET, time series. Landsat ETM+ 27/06/2023 image was used for validation and training. A 40.5 km x 40.5 km surface area centered on Cuza Voda village was selected. Also, this paper used (MERRA-2) (Modern-Era Retrospective Analysis for Research and Applications), which is the latest reanalysis of NASA's and Copernicus Atmosphere Monitoring Service (CAMS) that provides daily time series of meteorological data, including air average temperature (TA) at 2 m height, air relative humidity (RH), air pressure (p), average wind speed intensity (w),

and wind direction. In situ-monitoring spectroradiometrical additional data as well as meteorological observational data have been used. For similarity between two-time series data of the averaged daily air temperature (TA), and derived satellite biogeophysical parameters (LST, evapotranspiration-ET, and NDVI) in Cuza Voda this study used Spearman cross-correlation analysis and non-parametric test coefficients. The trend analysis of the time series for ET, NDVI, and LST in the Constanta Cunty from 2000 to 2023 can be conducted using a simple linear regression analysis method. This analysis aims to determine the trends (increasing or decreasing) over the specified period. For assessment of the normality of the averaged daily time-series data sets, Kolmogorov-Smirnov Tests of Normality were used. ORIGIN 10.0 software version 2021 for Microsoft Windows was used for data processing. For satellite data, ENVI 5.7 software was used.

4. RESULTS AND DISCUSSION

Constanta County study area in Dobrogea region is recognized as one of the most climate-sensitive regions in Romania, facing significant challenges in terms of water security. The arid areas and semi-arid areas dominate the landscape in South-Eastern parts of Romania, being highly susceptible to the impacts of global warming, resulting in more frequent, intense, and prolonged drought events. The increasing occurrence and severity of drought events in Dobrogea have had detrimental effects on agricultural and sparse vegetation. As a consequence, the vegetation ecosystem in this region has become extremely fragile, experiencing significant degradation that poses a considerable obstacle to achieving SDG goals. Therefore, monitoring vegetation resilience and vulnerability provides valuable insights into vegetation response to drought, aiding in the formulation of appropriate measures for the prevention and control of vegetation degradation.
Drought intensity was influenced by both drought severity and duration, resulting in complex patterns, especially during summer heat waves.
As the greatest component of water resources consumption, evapotranspiration (ET) plays a crucial role in connecting soil land surface hydrological processes and ecosystems, and it is also one of the essential parameters for evaluating surface drought information and surface-atmosphere heat exchange [14, 15]. Evapotranspiration has significant value in monitoring surface water availability and simulating land-atmosphere dynamic and thermal process interactions. ET represents the actual total amount of evaporation and transpiration in a specific region under natural conditions, and it is the sum of water surface evaporation, land surface evaporation, and plant canopy transpiration. Based on the temporal variation of MODIS Terra evapotranspiration of 8-Day ET during the 2021-2023 period in Cuza Voda centered test area (40.5 km x 40.5 km) in Constanta County. As Figure 2 shows, a decreasing trend of ET was recorded during the last years in the Dobrogea region, associated with the summer heat waves.

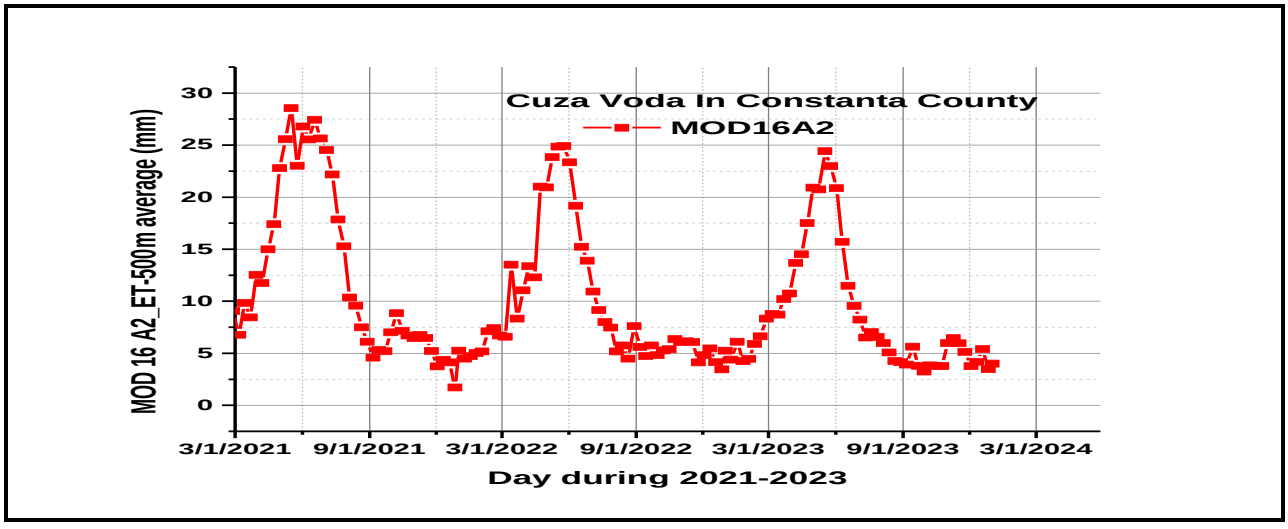

Figure 2. Temporal variation of MODIS Terra evapotranspiration of 8-Day ET during 2021-2023 period in Cuza Voda centered test area (40.5 km x 40.5 km) in Constanta County.

Also, for the entire 2002-2023 analyzed period this study found a positive Spearman rank correlation between the daily mean evapotranspiration ET and MODIS mean land surface temperature in the range ($r = 0.39$, $p<0.05$), and higher correlations between ETmax and LSTmax ($r = 0.83$, $p<0.05$). Strong positive rank correlations have been also recorded between the mean values of ET and the mean values of leaf area index-LAI ($r = 0.89$, $p<0.05$), as well as between the mean values of LAI and NDVI in the range of ($r = 0.88$, $p<0.05$). Low values of LAI, ET, and DVI correspond to moderate drought events, and very low values of these biophysical variables correspond to severe agricultural drought events. As can be seen in Figure 3, for the entire investigated period between 2021 and 2023, a strong positive Spearman rank correlation between the daily surface solar irradiance SI and air temperature TA in the investigated area, the Spearman correlation coefficients between SI and TA ($r = 087$; $p< 0.05$). The combined effect of hot and dry extremes can have disastrous consequences for the land cover vegetation and environment.

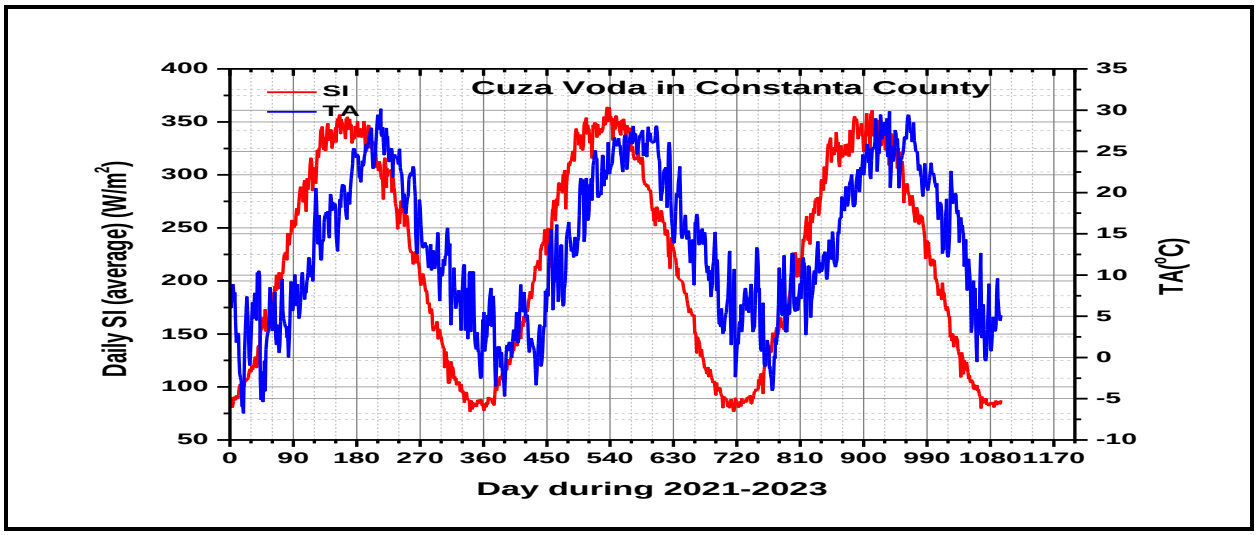

Figure 3. Temporal variation of the daily surface solar irradiance-SI and air temperature at 2m height-TA over 2021-2023 period in Cuza Voda in Constanta County.

For 2004-2023 time period over Cuza Voda in Constanta County, Figure 4 presents the temporal variation of the daily surface solar irradiance. The recorded Si daily maximum values were associated with heat waves in Romania during the years 2007, 2012, 2015, 2019, 2022, 2023.

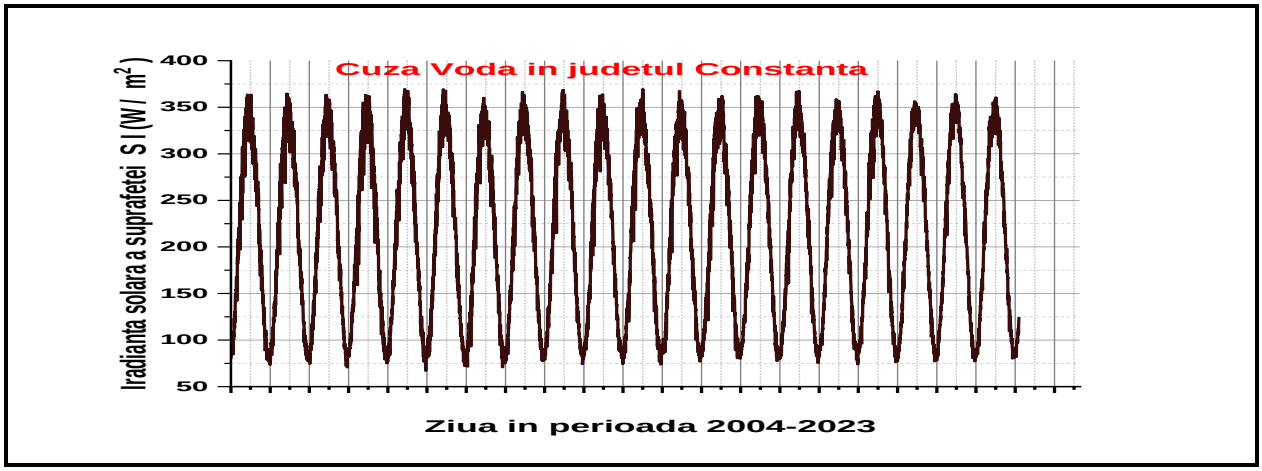

Figure 4. Temporal variation of the daily surface solar irradiance - SI and air temperature at 2m height -TA over the 2004-2023 period in Cuza Voda in Constanta County.

One of the key drivers of hot summers recorded in Romania, over the analyzed region, is the prevailing large-scale atmospheric dynamics, featuring an anticyclonic circulation over the central and eastern parts of Europe and enhanced atmospheric blocking activity associated with positive temperature anomalies underneath. Summer 2022 was one of the hottest recorded during the recent years [16, 17]. In terms of exposure and vulnerability to such climate-related risks (e.g., heat waves and droughts), the South-Eastern part of Romania, due to its geographical position and topographic features, is particularly affected by extreme climate.

The Spearman rank correlation analyses revealed that, at the pixel scale, during the summer season (June-August) TA and LST present a strong positive correlation (r= 0.89%, p<0.01). During summer periods (June – August) 2021-2023, the relationship between LST and NDVI appeared to be linear and negatively correlated in each year ranging from r = - 0.85 with p<0.05 in the 2022 year, r = - 0.77 with p<0.05 in the 2021 year, and r = - 0.40 with p<0.05 in the 2023 year. In Figure 5 can be seen a high decrease in NDVI values ranged (from 0.2-0.3) during summer-autumn periods of years 2022 and 2023.

The results of this study indicate the presence of agricultural droughts recorded during the last years in Constanta County, belonging to the Dobrogea region. Rising land surface temperature LST demonstrated significant negative effects on plants, with surface features playing a crucial role. However, NDVI time series data, do not provide a complete picture of drought severity, but drought monitoring and early warning systems can greatly benefit from the multi-temporal analysis of NDVI. Satellite-derived NDVI can be calculated using the red (low reflectance) and NIR (high reflectance) portions of the wavelengths, being recognized that green and healthy vegetation reflects less in the visible spectrum of the light during periods without drought due to high light absorption by chlorophyll, but reflects much lighter in the near-infrared (NIR) range due to specific scattering process by the inner leaf tissue and water content deficiency [18, 19].

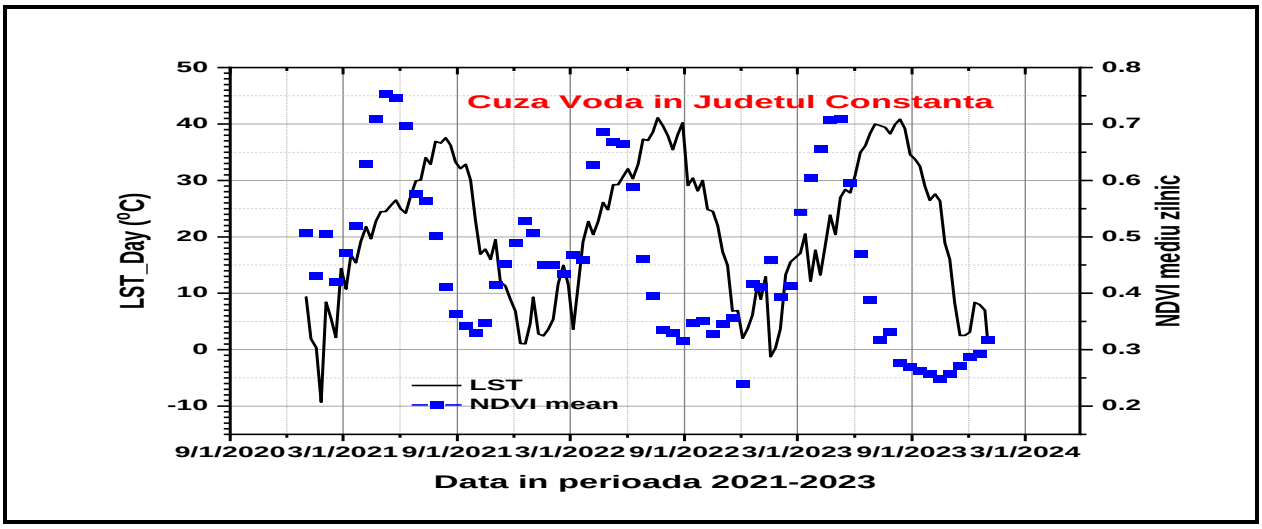

Figure 5. Temporal variation of the daily mean land surface temperature-LST and the daily mean Normalized Difference Vegetation Index -NDVI during 2021-2023 years in the Cuza Voda area.

Also, monitoring land surface albedo-LSA through MODIS Terra time series satellite MCD43A data shows that the Spearman rank correlation coefficient between the daily land surface albedo LSA and the daily average air temperature AT was negative (r= - 0.68; p< 0.01) per entire period 2004-2023. This study found that LSA is inversely correlated with the normalized vegetation index NDVI for the selected Cuza Voda area of 40.5 km x 40.5 km surface (r= -0.37; p <0.01). As a direct consequence, the healthy vegetation highly absorbs the incident sunlight (in the red region) and reflects less of it into the atmosphere. Also, the diseased plants reflect the light in the NIR range quite well. NDVI is a valuable tool for estimating LAI, but it is important to know its limitations. To obtain the most accurate estimates of leaf area index (LAI), it is advisable to use the NDVI in combination with other data sources, such as vegetation reflectance spectroscopy or in-situ spectroradiometrical measurements. Drought stress attributed to water deficit and hot air and land surface temperatures causes in plants a set of morpho-anatomical, physiological and biochemical changes, mostly

addressed to limit the loss of water by transpiration with the attempt to increase the plant water use, altering seriously the vegetation physiology, and finally leading to the decline of the crop productivity [20, 21].

5. CONCLUSION

This study found that with rising land surface temperature LST pattern, vegetation distribution changes noticeably in dryland areas. The relationship between LST and NDVI was used in this study to identify and assess agricultural drought for Constanta County in Dobrogea region. The significance of this study is to understand that drought events have a high negative impact on agriculture, water resources, soil features, and development. Remote sensing data are crucial tools to monitor drought with high resolution over large landcover areas and showed patterns in drought distribution during the study period in Constanta County in Romania. The semi-arid region Dobrogea is highly susceptible to drought due to its low annual precipitation rate and ecological vulnerability to climate change. The results from this study can help to understand driving mechanisms, which might lead to better predictability of these extreme events in the region, and advance our knowledge of the spatiotemporal variability of hot and dry summers associated with drought events over Romania with negative impacts on agricultural productivity and economy.

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