CAN REMOTE SENSING VEGETATION INDICES BE USED IN IDENTIFYING EROSION-PRONE AREAS?

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Abstract

In this study six vegetation indices were analyzed for Tutova Hills, years 2014-2023, highlighting spatio-temporal variations in the health of vegetation, soil moisture and surface temperatures, parameters directly correlated with land susceptibility to erosion.
Of the six indices, the one with the highest accuracy in detecting water stress and implicit areas with moisture deficit was NDII. This index correlates very well with high soil water content and the health of the vegetation, which makes it accurate in estimating the risk of erosion.
The conclusion is that such indices can be highly useful in predicting erosion-prone areas, because vegetation cover plays a major role in stabilizing soil and reducing erosion risk, being frequently integrated in erosion prediction models, from estimating RUSLE C-factor to temporal analyses or machine learning programs. Still, there are limitations related to data accuracy, but mostly to the need for an extensive field validation.

Keywords: vegetation indices, erosion, Landsat - 8 OLI/TIRS

Erosion-prone areas are regions that are highly susceptible to soil erosion, meaning the removal of the top layer of soil by water, wind or human activities. As a rule, these areas imply steep slopes, sparse vegetation cover, high rainfall or intense rainfall events, loose or loamy-sandy soils, poor land management (overgrazing, improper farming practices, hillsides cleared for agriculture etc.), semi-arid climate with strong winds, and little vegetation.

In short, erosion-prone areas are landscapes vulnerable to losing soil due to a combination of natural conditions and human influences.

Although erosion processes have been intensely studied in our study area (Tutova Hills - (Ioniță, 2000; Stângă, 2012; Niacșu, 2017; Niculiță, 2020), covering large surfaces in measuring soil erosion is time and energy consuming.

Our idea departed initially from a study regarding vegetation health but ended in including Remote Sensing (RS) and Geographical Information Systems (GIS) to identify and estimate erosion-prone areas.

Such an approach might prove helpful in the fast identification, followed by the validation on field of areas at risk, to finally propose and implement efficient measures of soil conservation and sustainable land management.

MATERIAL AND METHOD

Tutova Hills represent one of the regions of Romania characterized by a complex of interactions between natural environmental frailty and human-induced vulnerability, being among others highly exposed to erosion and land degradation. All the elements mentioned in introduction as defining erosion-prone areas are found alone or combined on large surfaces of the region. Most of the studies regarding erosion mention rates above the national means, reaching alarming values of up to 10 - 12 tons/ha of soil loss.

1. **Geospatial data processing**

The geospatial data used is available on online platforms. Computing the vegetation indices and biophysical parameters chosen for monitoring the vegetation state involved downloading multispectral satellite images of high accuracy, available for a longer period (in our case 2014-2023). LANDSAT-8 images have been downloaded using Google Earth Engine (https://earthengine.google.com).

The scenes used were recorded using three sensors: LANDSAT 7 TM, LANDSAT-8 ETM+ and LANDSAT-8 OLI. The scenes are divided according to the multispectral information intercepted in visible (RGB), near infrared (NIR), short-wave infrared (SWIR), thermal infrared (TIRS) and panchromatic (PAN). The images have

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a relatively fine spatial resolution (30 meters), with increased accuracy of the spectral details.

Each band offers unique characteristics depending on the wavelength and provides different results in mapping environmental components (differentiating bare soil from vegetation; evaluating vegetation development, plant vitality and health; differentiating biomass content, soil moisture, land surface temperature).

To have the most realistic results it is important to choose images in which the nebulosity is zero. The images were subjected to a sorting operation, in which a total of 334 images were selected from the total of 1050 downloaded. To reduce the time of downloading and processing, the R Studio tool library "landsat-util" was used.

Images have also a low temporal resolution, the satellite passing over the study area once every 16 days. After the sorting process, it was found that the number of images does not meet the minimum requirements to perform a coherent temporal analysis.

Thus, it was necessary to increase the nebulosity threshold by up to 50% for downloading the images. Using the Dineof algorithm from the sinkr R package (Beckers M. J., Rixen M., 2003), the data set was successfully reconstructed.

To have the same working format for all files, ArcGis Pro 3.0 was used for the automated extraction of vector and raster data according to the study area boundary. Data was reprojected using the arcpy module to avoid pixel distortion in the spectral bands and reprojected according to the Romanian coordinate system (Datum Dealul Piscului 1970 - Stereo 70 projection - EPSG 31700 code). The script was run as a batch process to have the same working structure for all files.

2. **Vegetation indices and biophysical indicators**

Spectral observations can easily help identifying the level of stress, health and radiative reflectance of vegetation. Simple numerical indicators, they reduce multispectral data by combining the values of different spectral bands to a single variable, for the prediction and evaluation of vegetation characteristics (Bannari *et al*., 1995).

Six spectral indices recognized for the increased degree of accuracy in monitoring vegetation and soil water and thermal conditions were used and applied, namely: Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Normalized Difference Infrared Index (NDII), Normalized Difference Moisture Index (NDMI), Vegetation Health Index (VHI) and Land Surface Temperature (LST) (IDB, 2023; Kai *et al.*, 2023). Formulas for all indices are available at https://www.indexdatabase.de/db/i.php.

The automated calculation of the indices was performed with the help of ArcGis Pro 3.0 and the Python workflow for the multiannual period, the average annual warm season and multiannual warm season.

NDVI is a numerical indicator of the amount and vigor of vegetation, effective for agricultural lands, dense forest, semi-arid areas. It can be used in vegetation monitoring applications such as evaluating crop growth patterns, biomass quantity, photosynthetic activity, and the percentage of land cover with vegetation. NDVI values range between -1 and 1; with negative ones indicating clouds or water, and positive values approaching 0 indicating areas not covered by vegetation.

NDWI is used to detect water bodies, with values >0.3 for aquatic surfaces and between -1 and 0 for vegetated surfaces. It is designed to delimit the boundaries of aquatic surfaces and the distribution of suspended sediments.

NDII is used to extract impervious surfaces, being used in drought monitoring and the assessment of agricultural land and forest health.

VHI estimates the health and condition of vegetation and the impact of drought on agriculture, being a comprehensive indicator of vegetation vigor or stress. It is a combination of the Vegetation Condition Index (VCI) and the Thermal Condition Index (TCI). The two sub-indices reflect the moisture and thermal conditions, respectively.

NDMI is useful in monitoring soil moisture and vegetation, having wide applications in drought monitoring, water management in agriculture, forest fire risk assessment and climate change prediction.

LST represents the temperature of the land surface, helping in delineating vegetation canopies, soil and built-up areas, and is influenced by factors such as solar radiation, land cover, vegetation density, soil moisture and atmospheric conditions. It is a critical parameter in the assessment of surface energy balance and drought monitoring.

RESULTS AND DISCUSSIONS

Analysis of vegetation indices and land surface temperature (LST) for the Tutova Hills (2014-2023) reveals consistent spatial and temporal patterns influenced by precipitation, temperature, humidity and solar radiation. Across all indices, a clear contrast emerges between the northwestern (NW) and central-northern (CN) sectors, characterized by dense, moisture-rich vegetation, and the southeastern (SE) and central-southern (CS) sectors, where vegetation is sparse and soil vulnerability is high.

High NDVI values (0.65–>0.70) dominate the NW and CN areas, corresponding to forests and meadows above 300 m altitude with limited agricultural use. Low values (-0.45 - 0.50) occur in the CS and SE sectors, particularly on SE and SW slopes, reflecting intensive agriculture, poor vegetation cover, and exposure to erosion.

NDWI (*fig. 1*) and NDII show similar spatial patterns, with maximum values in the NW and CN regions, indicating high vegetation water content, while SE and S areas exhibit low values, consistent with deforested slopes and water stress.

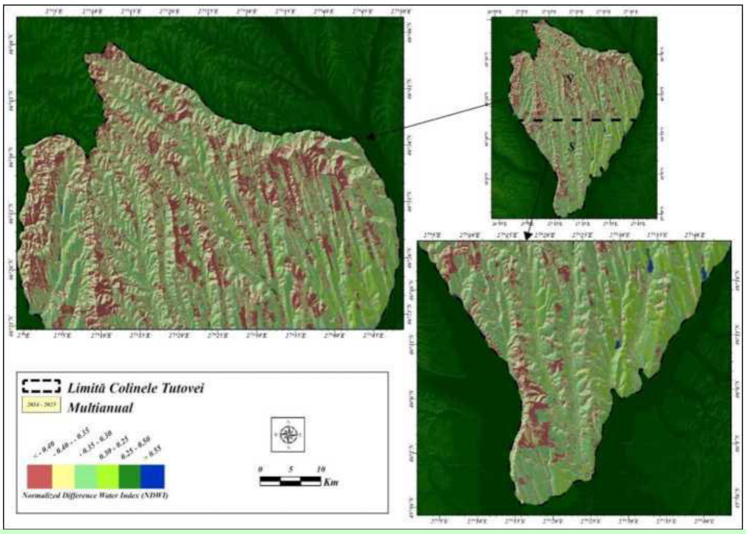

Figure 1 **Spatial distribution of the NDWI mean multiannual values**

NDMI and VHI confirm these patterns: NW sectors maintain high moisture and vegetation health, whereas SE areas show water stress, vegetation degradation, and elevated risk of crop disease.

The LST index highlights thermal contrasts, with high temperatures (24–26 °C) on SE slopes and degraded lands versus lower values (13-16 °C) in NW vegetated zones, reflecting the moderating effect of denser vegetation.

During the summer season, spatial variability is more pronounced. Multiannual NDVI peaks above 0.79 in the NW, indicating dense vegetation, and drops below 0.45 in the SE, where steep slopes, geomorphology, and land use exacerbate water stress and erosion. NDWI highlights soil and vegetation moisture deficits, particularly in interfluves with rapid runoff, while valleys retain higher humidity.

NDII confirms low water availability in southern sectors due to high temperatures, low rainfall and higher values of evapotranspiration. NDMI further identifies areas of water stress and erosion risk, and VHI captures the combined effect of thermal and hydric stress on vegetation health. LST (*fig. 2*) shows extreme surface heating in the SE (33-35°C), whereas the north experiences cooler conditions (<23°C), reinforcing the link between vegetation cover, soil protection, and thermal regulation.

Temporal analysis of annual summer values over 2014-2023 reflects the impact of climatic variability on vegetation and soil moisture. NDVI had values above average during 2014-2016, supported by moderate summer precipitation, while drought and high temperatures in 2017–2018 caused sharp declines in vegetation cover, particularly in central and southern areas.

The period 2021–2023 showed alternating years of stress and recovery, with 2021 marked by prolonged drought and thermal stress, followed by improved vegetation growth in 2022–2023. NDWI and NDII mirrored these trends, reflecting moisture availability and soil vulnerability, whereas NDMI highlighted vegetation recovery and erosion-prone areas.

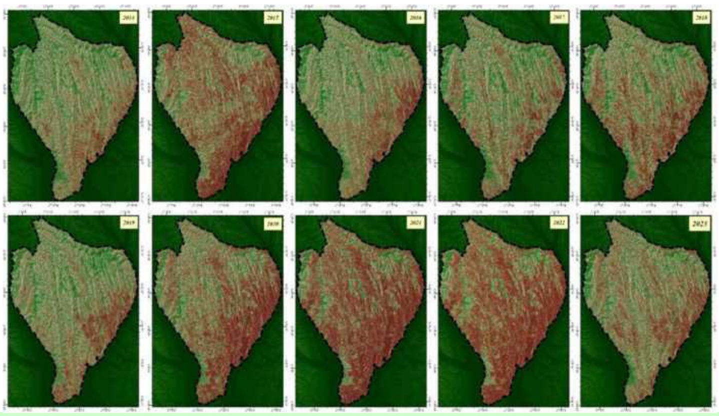
Figure 2 **Spatial distribution of mean annual values in the summer season of LST**

VHI integrated vegetation and thermal stress patterns, with high values in favorable years (2014 - 2016) and low values during drought episodes (2017, 2020–2022). LST captured thermal extremes (30–36 °C in the hottest years) and, when combined with spectral indices, provided a comprehensive view of vegetation health, water stress, and soil vulnerability, despite some limitations due to atmospheric conditions.

Overall, the integrated analysis of NDVI, NDWI, NDII, NDMI, VHI, and LST demonstrates that the NW and CN sectors of the Tutova Hills maintain denser, healthier and moisture-rich vegetation, while the SE and CS areas are prone to water stress, vegetation degradation, and soil erosion, particularly during dry, high-temperature summers. These findings emphasize the need for targeted water and vegetation management strategies to mitigate soil degradation and support sustainable land use.

CONCLUSIONS

In this study, six vegetation indices were analyzed for the period 2014 - 2023, highlighting spatio-temporal variations in the health of vegetation, soil moisture and surface temperatures, parameters directly correlated with land susceptibility to erosion.

Of the six indices, the one with the highest accuracy in detecting water stress and implicitly areas with moisture deficit was NDII. This index correlates very well with high soil water content and the health of the vegetation, which makes it extremely accurate in estimating the risk of soil erosion.

Multiannual averages provided an overall mosaic image for the study period. The data obtained correlates with areas affected by erosion, validated by literature data. The accuracy of this dataset for general assessments is vast but limited for spatial detail.

The conclusion is that such indices can be highly useful in predicting erosion-prone areas because vegetation cover plays a major role in stabilizing soil and reducing erosion risk.

Still, there are limitations related to data accuracy, but mostly to the need for an extensive field validation or comparison between the areas identified as prone with existing inventories of eroded soils, landslides or other degradation processes.

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