EVOLUTION OF CLIMATIC PARAMETERS OVER THE LAST FIVE DECADES (1974–2023) AND THEIR ENVIRONMENTAL IMPACT IN THE INEU ADMINISTRATIVE UNIT

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RESEARCH ARTICLE

Abstract

The paper examines the dynamics of the principal climatic parameters recorded over the last five decades (1974–2023), focusing on the annual mean temperature and the total annual amount of precipitation, which are considered essential indicators of the thermal and pluviometry regimes. The meteorological data were processed based on records from the Oradea station, which shares a similar geographical and climatic context with the Ineu Administrative-Territorial Unit (ATU), thereby facilitating the extrapolation of results to the local level. Preliminary results reveal an upward trend in temperatures and a pronounced variability in the fluviometric regime, marked by periods of accentuated water deficit over the last two decades. For an integrated perspective, the study utilizes GIS and remote sensing technologies, generating spatial maps through the NDVI (Normalized Difference Vegetation Index) and NDMI (Normalized Difference Moisture Index). These tools offer a supplementary analysis of vegetation evolution and soil moisture fluctuations within the Ineu ATU. The integration of meteorological data with spatial analysis allows for a comprehensive assessment of climate and environmental change, highlighting general trends and areas vulnerable to climatic stress and ecosystem alterations.

Keywords: annual mean temperature, annual precipitation, climatic parameters, GIS, NDVI, NDMI, remote sensing, water deficit
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INTRODUCTION

The Oradea Meteorological Station possesses an extensive climatic series, spanning the period 1974–2023, which facilitates a detailed analysis of the long-term evolution of atmospheric conditions characteristic of the western region of Romania. Temperatures and precipitation are established as essential climatic indicators, enabling the identification of trends and consequences of climate variability at both the regional and local scales.

By processing this data, the study reveals a clear picture of the transformations within the thermal and pluviometry regimes, serving as a foundation for understanding climatic warming processes and their effects on the local ecosystem.

The Ineu Administrative-Territorial Unit (ATU), situated in the proximity of the municipality of Oradea, benefits from a similar geographical and climatic context, which validates the extrapolation of the results obtained. This spatial correspondence provides the research with an applicative character, with direct implications for territorial planning strategies and adaptation to climate change in the Ineu area.

MATERIAL AND METHOD

The analysis was conducted in two principal phases: the temporal processing of meteorological data (Babak , Hossein , Rajmund, & Aleksandra, 2025) and the spatial integration through GIS (Juntao , Chuntian, & Shen, 2024) and remote sensing technologies.

Meteorological Data Processing

To highlight the evolution of annual mean temperatures and the average precipitation level (Monica & Nagavciuc, 2021) a graph was created in Excel (Figure 1).

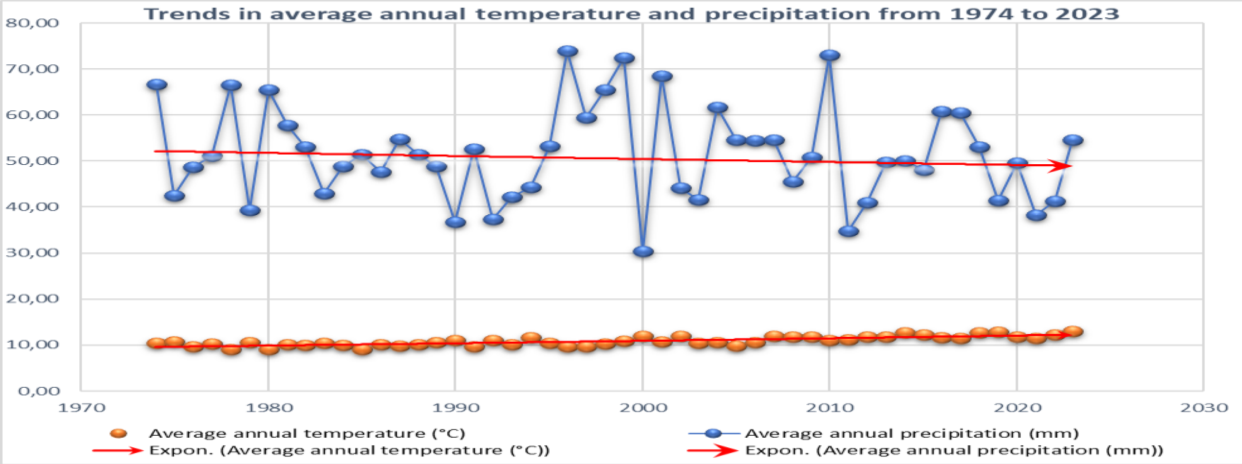

Figure 1. **The evolution of annual mean temperatures and the annual mean precipitation during the 1974–2023 period.**

The meteorological data, sourced from the Oradea station and covering the 1974–2023 interval, include monthly values for the mean temperature and total precipitation (Giovenale , Chloe, Jan, & Rachel, 2025). Processing was performed in the Python programming language (version 3.12), utilizing specialized libraries such as Pandas (for data management) and Matplotlib (for graphical visualizations of temporal evolution).

The annual mean temperature was calculated as the arithmetic mean of the monthly values:

$$T_{\text{annual}} = \frac{\sum_{i=1}^{12} T_i}{12}$$

and the mean annual amount of precipitation was determined using the following relation:

$$P_{\text{annual}} = \frac{\sum_{i=1}^{12} P_i}{12}$$

where T (annual) represents the mean monthly temperature, and P (annual represents the monthly precipitation (mm). The data were checked for integrity by excluding incomplete values (e.g., "-999") and rounding the results to one decimal place for consistency.

The statistical analysis included the determination of the overall mean for the entire period, the identification of extremes (minimums and maximums), and the evaluation of temporal trends through simple linear regression. To evaluate the relationship between the annual mean temperature and the total annual amount of precipitation, an Ordinary Least Squares (OLS) linear regression was applied to the Oradea climatic series for the 1974–2023 interval. The mean monthly temperatures and monthly precipitation were aggregated annually, and the functional relationship was expressed as:

where:

P= annual precipitation (mm)

T= annual mean temperature (°C)

β_0, β_1= model coefficients

ϵ= residual term

$$P = \beta\_0 + \beta\_1\, T + \epsilon$$

The analysis was performed in Python, utilizing the Pandas and Stats models libraries, including verification of statistical significance (test t) and model quality (coefficient of determination R^2). The significance of the correlation level was evaluated at p < 0,05.

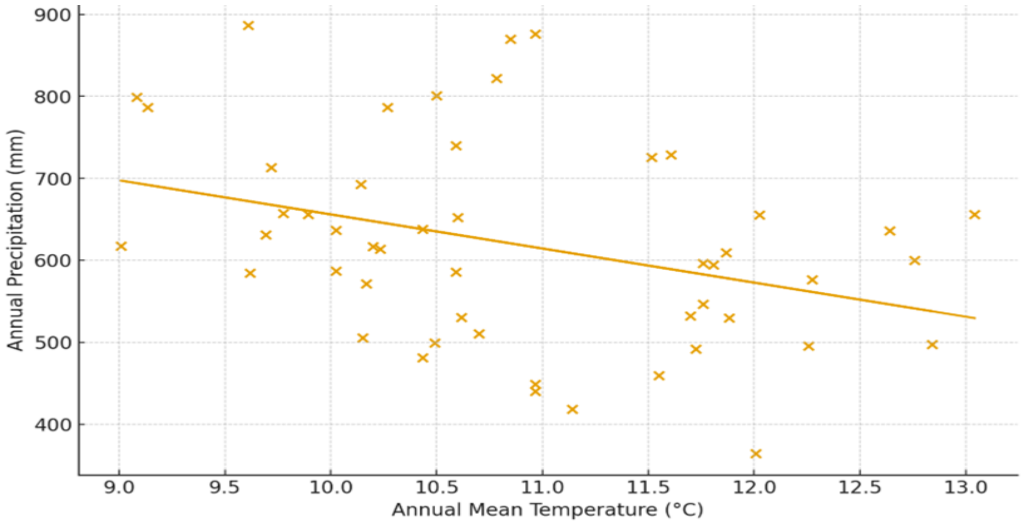

Figure 2. **OLS Regression: Precipitation vs. Annual Mean Temperature, Oradea 1974–2023**

Parameter	Value
Temperature Coefficient	−41.58 mm / °C
Intercept	1071.70 mm
R^2	0.119
P - value	0.014 statistically significant
Observations	50 years

Interpretation:

- For every 1°C increase in the annual mean temperature, precipitation decreases by approximately 41.6 mm/an.
- The relationship is statistically significant ($p < 0.05$)
- $R^2 = 0.119$ → Temperature explains approximately 12% of the variability in precipitation (which is typical for multiannual climatic studies, as climate is multivariate)

The results of the simple linear regression (OLS) for the 1974–2023 period indicate a negative relationship between the annual mean temperature and the total annual amount of precipitation in the Oradea area, thus confirming the climatic tendency towards a warmer and drier climate. For every 1°C increase in the annual mean temperature, the mean precipitation amount decreases by approximately 41,6 mm/an.

The relationship is statistically significant ($p = 0.014$), suggesting a robust long-term climatic correlation. This analysis supports contextual observations regarding the intensification of drought phenomena and pluviometry variability, with direct implications for water resource management, agriculture, and adaptive planning (Linsenmeier, 2024).

Spatial Analysis using GIS and Remote Sensing

For the spatial component, the QGIS software (version 3.34) (Subhajit, Kundan , & Preet, 2025) was utilized, which facilitated the processing of satellite imagery and the elaboration of thematic maps for the UAT Ineu.

To provide a suggestive visualization of the difference in vegetation status and density as well as soil moisture and hydric stress-resulting from the effects of climate change and the climatic tendency toward a warmer and drier climate-a comparative analysis was performed for the last 10 years, referencing August 2015 and August 2025 (Figure 1, Figure 2, Figure 3, Figure 4).

The imagery sources included the Copernicus Browser-Sentinel 2 archives (Antonio , et al., 2024) with a 20 m resolution, spanning the 2015–2025 interval, accessed through open platforms such as Esri Maps - Environmental System Research Institute, ensuring transparency and open access to data.

The indicators evaluated are the **NDVI** - Normalized Difference Vegetation Index (Ana-Maria, Catalin , Bogdan, & Florin, 2024) and the **NDMI** - Normalized Difference Moisture Index (Berca & Roxana, 2022)

To ensure spectral and temporal consistency, atmospheric corrections (DOS and

6S algorithms), cloud filtering (QA band mask), and normalization of spectral values were applied.

Data Integration: The climatic parameters (temperature and precipitation) were spatially correlated with the NDVI and NDMI indices through overlay operations in QGIS, analyzing relationships such as the impact of reduced precipitation on NDMI (hydric deficit) and the influence of increased temperatures on NDVI (thermal stress on vegetation)

The NDVI Index was utilized for the evaluation of vegetation status and density, calculated according to the formula:

$NDVI = (NIR - Red)/(NIR + Red)$

where NIR represents the Near-Infrared band and Red represents the Red band. NDVI values were determined for seasonal periods (summer, autumn) in order to identify temporal changes in vegetation cover.

The Normalized Difference Vegetation Index is a simple yet efficient index for quantifying green vegetation. It serves as a measure of vegetation health, based on how plants reflect light at specific wavelengths. The value range for NDVI is from -1 la 1. Negative NDVI values (approaching -1) correspond to water. Values close to zero (-0,1 till la 0,1) generally correspond to bare areas of rock, sand, or snow. Small positive values represent shrubs and grasslands (approximately 0,2 till 0,4), while high values indicate tropical and temperate forests (values approaching 1).

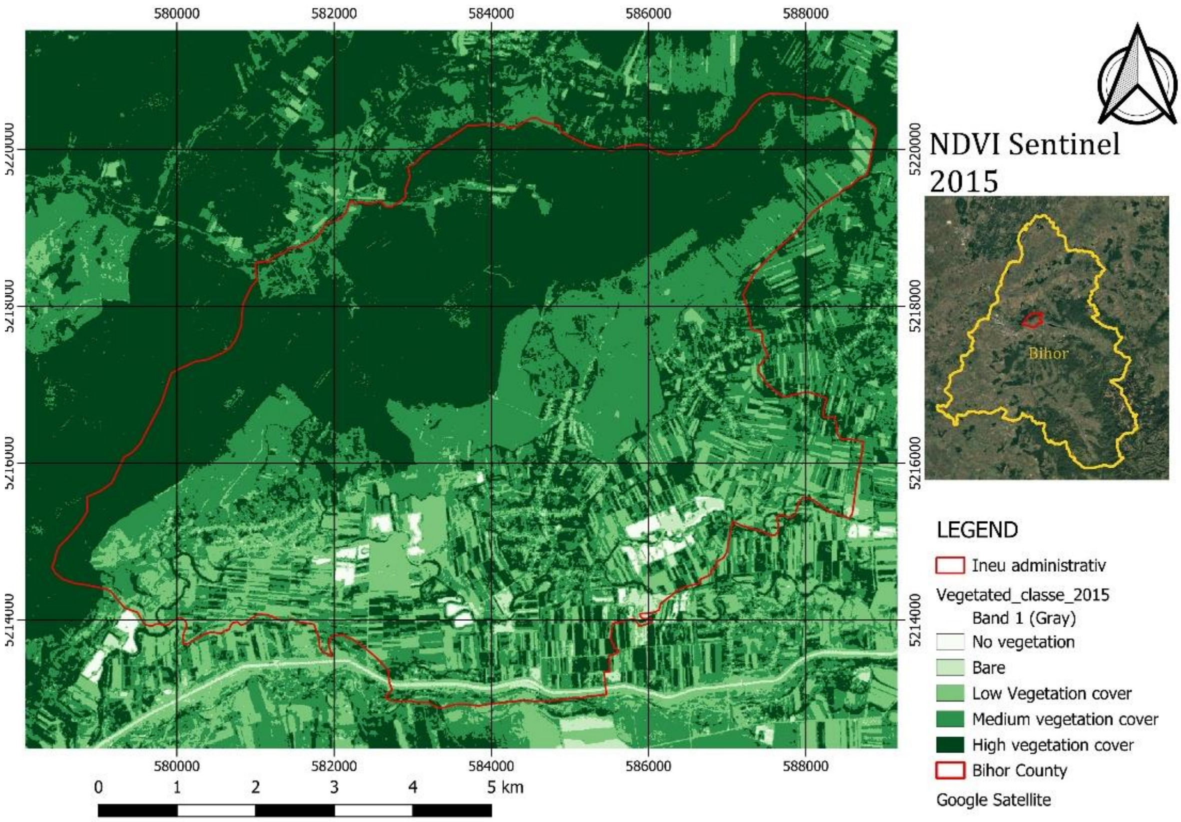

Figure 1. **Vegetation Status and Density Assessment (NDVI 2015)**

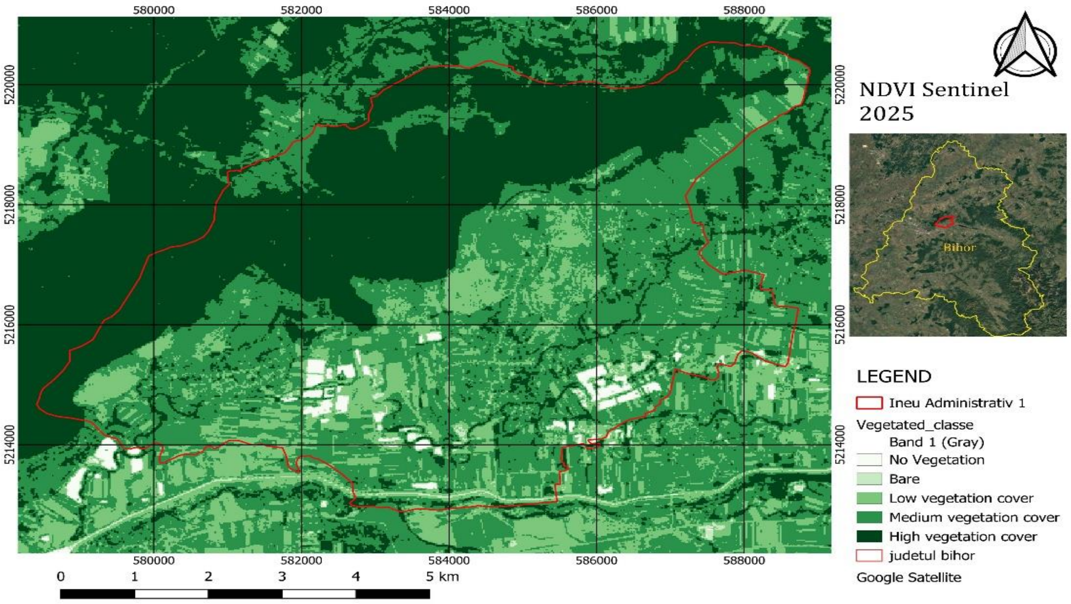

Figure 2. **Vegetation Status and Density Assessment (NDVI 2025)**

From the captured imagery, a decrease in vegetation density can be observed in 2025 compared to 2015, which is objectified by extensive areas highlighted in the yellow color (Figure 1, Figure 2).

The NDMI Index was applied for the analysis of soil and vegetation moisture, according to the following relation:

$$NDMI = (NIR - SWIR)/(NIR + SWIR)$$

where SWIR designates the Shortwave Infrared band. NDMI values were calculated and cartographically represented across the UAT Ineu (approx. 10 km^2 – total analyzed area), highlighting zones exposed to moisture deficit or thermal stress.

The NDMI Index can be utilized for detecting hydric stress and for monitoring irrigation and/or soil moisture. For all index values greater than 0, knowing the type of land use and cover, it is possible to determine whether irrigation has occurred or whether soil moisture is optimal. Furthermore, by knowing the crop type (e.g., citrus crops), one can identify the efficiency of irrigation during the critical summer growing season and highlight areas of the farm that are sub- or over-irrigated.

The comparative imagery objectifies the decrease in soil moisture and the associated hydric stress, colored in yellow to reddish tones, characteristic of 2025 compared to 2015 (Figure 3, Figure 4).

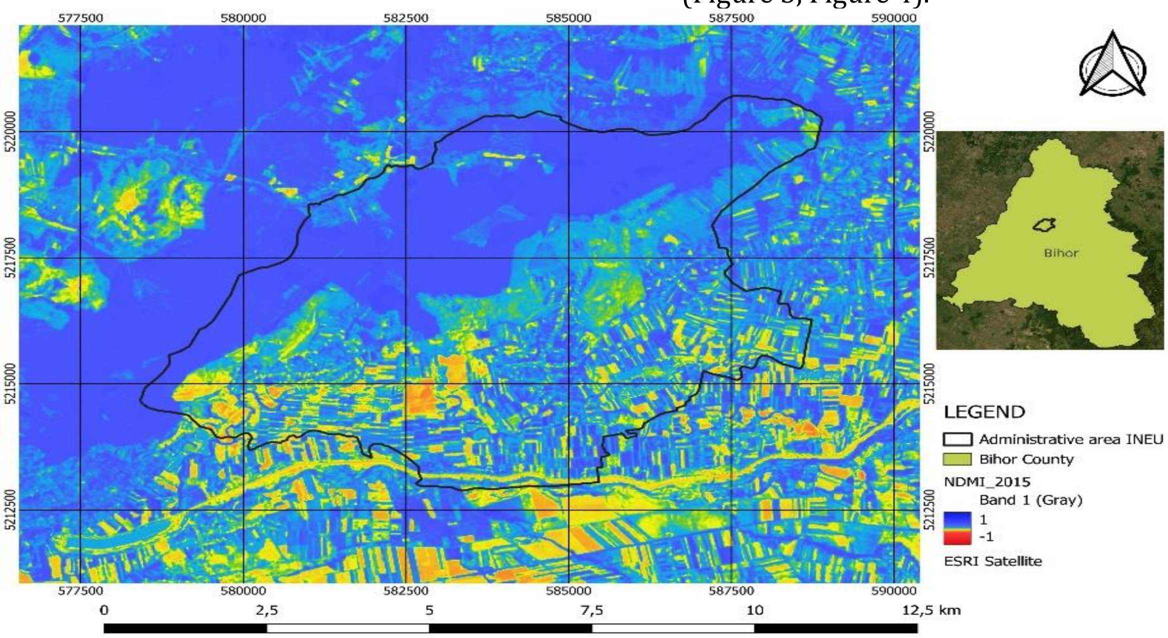

Figure 3. **Soil and Vegetation Moisture Status Assessment (NDMI 2015)**

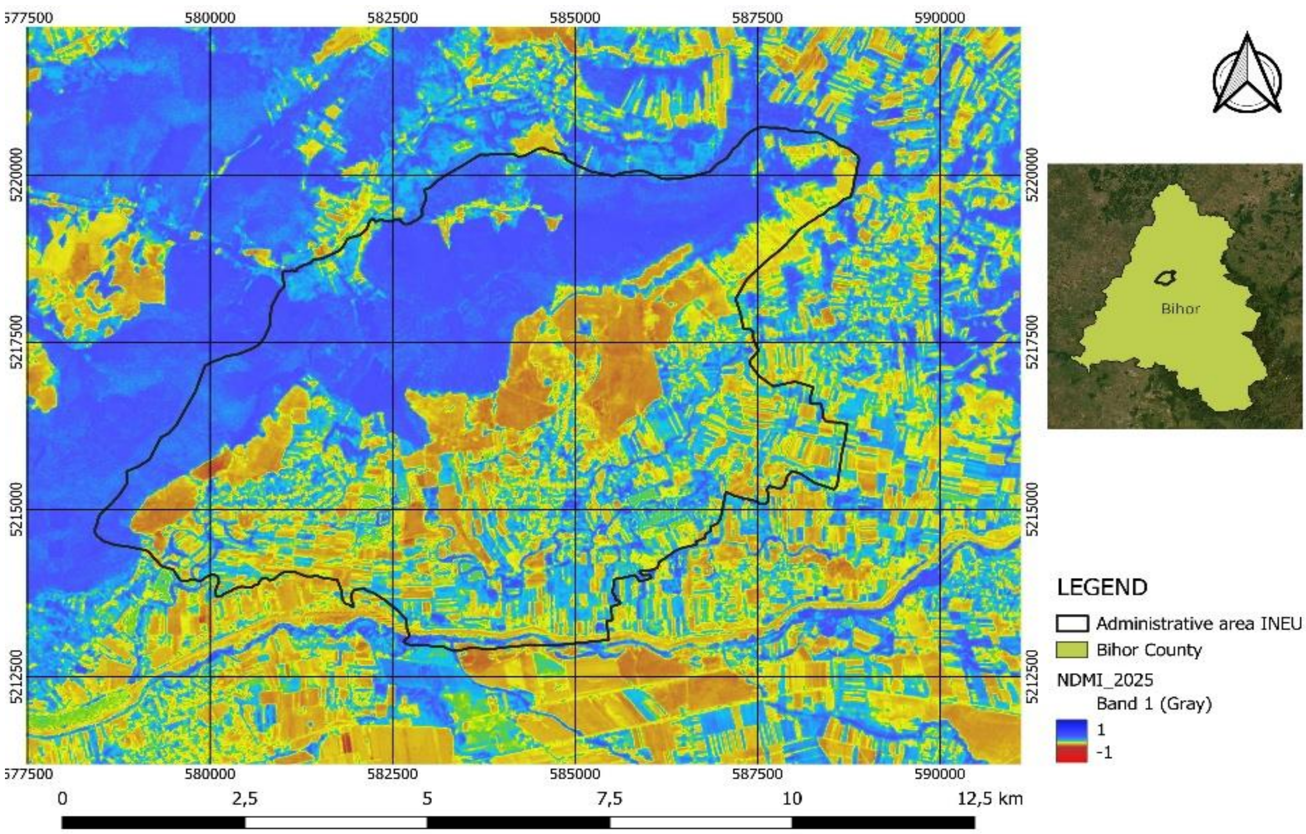

Figure 4. **Soil and Vegetation Moisture Status Assessment (NDMI 2025)**

RESULTS AND DISCUSSIONS

The analysis of the climatic parameter evolution for the 1974–2023 interval clearly highlights modification trends in the thermal and pluviometry regimes within the analyzed area. The annual mean temperature demonstrates a constant long-term increase, with a visible intensification over the last two decades. The linear regression results indicate an average annual rate of temperature increase, which confirms the regional warming trend, consistent with climatic observations at the national and European levels. In paralel, precipitation variabili is pronounced, featuring episodes of severe hidric deficit, particularly after the year 2000, alternating with isolated wetter years. This indicate an increasingly instabile and hard-to-anticipate climate.

From a spatial perspective, the mean NDVI values processed for the vegetative seasons indicate a slight decrease in vegetation vigor across certain portions of the Ineu ATU, particularly in intensively utilized agricultural areas and near lands experiencing high anthropogenic pressure. This tendency can be correlated with the reduction in water resource availability and the increased thermal stress on local ecosystems. The NDMI values support this conclusion by highlighting a higher frequency of zones with soil moisture deficit, especially during consecutive dry years, which can affect agricultural productivity and the resilience of natural vegetation.

The linear regression results emphasize a statistically significant negative relationship between the annual mean temperature and the total annual amount of precipitation. The model demonstrates that, over the 50 analyzed years, the rise in mean temperatures was associated with a decline in precipitation:

These results indicate that a 1° increase in the annual mean temperature is associated with a reduction of approximately 41,6 mm in annual precipitation. The R^2 value suggests that approximately ~12 of the precipitation variability is explained by temperature - a typical level for multifactorial climatic systems.

The observed trend confirms the shift towards a warmer and drier regional climate, with direct relevance for local agriculture, water resources, and biodiversity. These findings are congruent with recent literature concerning the climatology of Central and Eastern Europe, which reports similar scenarios of increasing temperatures and heightened hydric pressure.

The integration of climatic results with remote sensing analysis underscores the importance of adaptation to climate change for the sustainable management of natural resources. The identified trends are relevant in the context of Sustainable Development Goals (SDGs), particularly SDG 13 – "Climate Action", SDG 15 – "Life on Land", and also SDG 6 – "Clean Water and Sanitation", given the increasing pressure on water resources. The precipitation variability, correlated with the decline in spectral-ecological indices in some areas, indicates potential risks for ecosystem stability and the necessity for agricultural practices adapted to hydric stress phenomena, in accordance with the principles of sustainable land management and the strategic national provisions (e.g., The National Strategy for Sustainable Development, 2030).

These results also align with the objectives of SDG 11 – "Sustainable Cities and Communities", through the need for local interventions aimed at increasing the resilience of rural and urban communities to the effects of climate change, as well as improving green infrastructure and protecting agricultural lands.

CONCLUSIONS

The study demonstrates that during the 1974–2023 interval, the analyzed territory is subject to gradual climatic warming, accompanied by an increase in the variability of the pluviometry regime and increasingly frequent episodes of hydric deficit. These transformations directly influence the dynamics of vegetation and the capacity of ecosystems to respond to climatic stress, an aspect confirmed by the analysis of the NDVI and NDMI indices. High-vulnerability areas require continuous monitoring and the implementation of adaptive measures, particularly in the agricultural sector, where water use efficiency, crop diversification, and soil conservation techniques become essential.

The statistical analysis confirms the existence of a significant inverse relationship between the annual mean temperature and the total annual precipitation for the 1974–2023 period at the Oradea station. The results support the hypothesis of the intensification of the regional thermal regime and the reduction of pluviometry resources, thus arguing for the necessity of local climate adaptation strategies.

In the context of sustainable development, the results support the need to consolidate local strategies oriented towards the protection of natural resources and the adaptation of communities to climate change. The contribution of this research falls in line with promoting responsible environmental management, aligned with SDG 6 (Clean Water and Sanitation), SDG 11 (Sustainable Cities and Communities), SDG 13 (Climate Action), and SDG 15 (Life on Land), highlighting the importance of GIS and remote sensing tools as technical support for monitoring and decision-making.

Therefore, the integration of statistical climatic modeling with spatial analysis (NDVI/NDMI) contributes to a deeper understanding of local ecosystem vulnerabilities and supports the foundation of measures for climate change mitigation and adaptation.

In the medium and long term, it is recommended to continue regional climatic studies, correlate them with pedological and economic information, and integrate the results into local land-use planning and sustainable agriculture schemes. This approach will contribute to increased resilience against future climatic challenges.

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