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Romania's climate dynamics and future projections

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Abstract
Climate change is a hot topic these days in all countries around the world. Although Romania has taken important steps to combat climate change, continued efforts are needed to implement existing policies for monitoring and forecasting climate parameters, as well as to raise population awareness. In this paper, several climatic parameters are analyzed, such as mean annual air temperature, average minimum and maximum temperatures per month, mean temperature during the vegetation season, annual amount of precipitation, amount of precipitation per month and amount of precipitation during the vegetation season. Climatic parameters were studied over four periods: 1901-1930, 1931-1960, 1961-1990 and 1991-2023. Temperatures were also estimated until the year 2100. Projected future temperatures were estimated by combining data found in the current databases and Representative Concentration Pathways (RCP) projection data. Some ecoclimatic indices were calculated, such as De Martonne aridity index and the Lang rainfall index. To achieve the objectives of this study, the following databases were used: World Bank Climate Knowledge Portal, European Environment Agency (EEA), Our World in Data, European Drought Observatory (EDO), European Climate Assessment & Dataset.

Keywords: climate dynamics, thermal and rainfall trends.

1. INTRODUCTION

Romania has experienced significant warming of the air and an increase in extreme temperatures, concomitant with changes in the precipitation regime, over the last century. National and regional studies indicate more pronounced warming trends during the hot season, an extension of the vegetation season, and more pronounced alternations between episodes of drought and torrential rains, with signs of aridification in the south and east [1]. A statistically significant increase in the average annual temperature and daily maximum temperatures was observed, with a more pronounced effect in summer and in large cities [1]. Ionita et al. analyze heat waves (HW) in Eastern Europe over a long period to contextualize the record-breaking summer of 2023. Attribution analysis indicates that the extreme temperatures of 2023 would not have been possible without anthropogenic climate change and that, by the end of the century, such temperatures will occur annually. Expanding historical archives proves essential for a nuanced understanding of HW dynamics [2].

In this context, understanding climate dynamics—both thermal and rainfall trends, as well as interannual and seasonal variability—becomes essential for underpinning public policies, managing water resources, agriculture, and public health, as well as for planning adaptation to climate change. Romania offers a diverse climate laboratory, from the Carpathian Mountain areas to the plains and coast, which requires a careful analysis of the climate signal against a background of pronounced spatial heterogeneity.

The current state of research reveals a consensus regarding the increase in the average annual temperature and changes in the temporal distribution of precipitation, with an emphasis on the intensification of heat waves, the extension of the vegetation season and a more marked alternation between episodes of drought and torrential rains. National and European studies indicate faster warming in the warm season, along with high rainfall variability, including regional signals of aridification in the south and east. At the methodological level, recent literature combines long-term observational series with reanalysis, gridded sets and satellite products, and for the future uses emission/forcing scenarios (RCP/SSP) to project possible temperature and rainfall trajectories. In parallel, ecoclimatic indicators—such as the De Martonne aridity index and the Lang rainfall index—are used to translate the climate signal into biogeographic and agro-climatic implications.

Despite all the progress, several important gaps persist: insufficient spatial resolution to capture local contrasts, uncertainties in rainfall projections, especially in summer, and limited integration of extremes (duration, intensity, persistence) in sectoral risk assessments. Also, harmonization between different databases and ensuring the quality control of the series remains critical for long-term comparability.

In this context, the present article aims to (1) characterize the evolution of a set of key climate parameters—annual mean temperature, monthly minimum and maximum, growing season temperature, annual precipitation, monthly and growing season precipitation; (2) estimate thermal trajectories up to 2100 by combining observational series from the main climate portals with projections based on RCP scenarios; and (3) assess the ecoclimatic implications by calculating the De Martonne and Lang indices. The analysis is based on public reference datasets (international and European platforms, national networks), subject to control and aggregation procedures appropriate to the periods studied.

By combining historical perspective with future scenarios, the study contributes to clarifying climate trends in Romania and provides a coherent basis for sectoral assessments (agriculture, water resources, health, infrastructure), as well as for further calibrations of adaptation and mitigation strategies. The results are discussed in terms of practical utility and inherent uncertainties, with a focus on relevance for decision-makers and the scientific community.

2. EXPERIMENTAL

The data used in this study come from many databases, such as the World Bank Climate Knowledge Portal, European Environment Agency (EEA), Our World in Data, European Drought Observatory (EDO) and European Climate Assessment & Dataset.

Projected Future Temperatures were estimated by combining data found in the current databases and Representative Concentration Pathways (RCP) projection data.

Data processing and preprocessing, including outlier detection, aggregation, and basic correlation analysis, were performed using Statistica 8.

Some ecoclimatic indices were calculated, such as De Martonne aridity index and the Lang rainfall index.

The De Martonne aridity index [3] is an indicator used to assess the degree of aridity or humidity of a climate in each region. It is based on the ratio of precipitation to the average annual temperature of an area.

$$I_{De\ Martonne}=P/(T+10) \quad (1)$$

where: $\mathbf{I_{DeMartonne}}$ is De Martonne aridity index, P the total amount of annual precipitation (in mm), T average annual temperature (in degrees Celsius).

The Lang pluviometric index [4] is a climate indicator that expresses the ratio between annual precipitation and average annual temperature.

$$I_{Lang}=P/T \quad (2)$$

The difference between the De Martonne Aridity Index and the Lang Pluviometric Index lies in the method of calculation, the units involved.

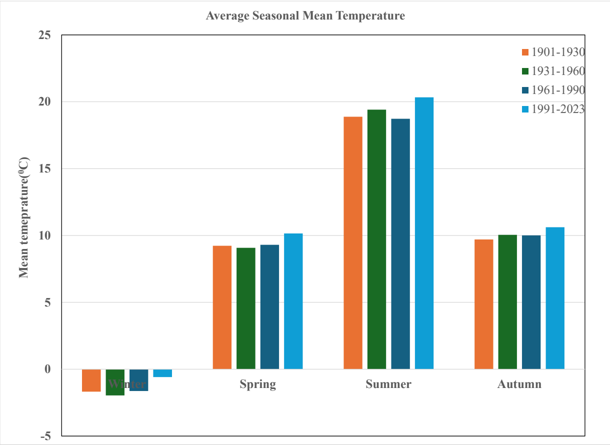
The coefficient of variation (CV) measures the "relative spread" of data from its mean:

$$CV=(\sigma/\mu)\times 100 \quad (3)$$

where σ is the standard deviation (of values (e.g. temperatures or precipitation), μ mean of the values.

3. RESULTS AND DISCUSSION

Fig. 1 shows the evolution of the average seasonal mean temperature and the dynamics of the average seasonal maximum temperature for the three time periods studied.



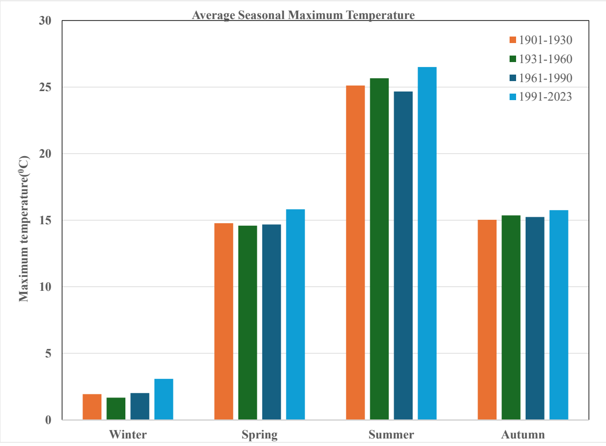


Fig.1. The dynamics of the average seasonal mean and maximum temperature

The data show a slow but steady increase in average seasonal temperatures, especially in the warm seasons (spring and summer). In winter, there was an increase in maximum temperatures from about 2°C at the beginning of the 20th century to 3.5–4°C after 1990. In spring, there was an increase in temperatures in the period 1991–2023, to ≈16°C.

In summer, a pronounced increase is observed after 1990 from ≈25°C to ≈27°C. In the last studied period, more frequent and more intense heat waves occurred. In the autumn season, a slightly increasing trend is observed, which led to the extension of the warm season. In conclusion, the general trend would be an increase in seasonal maxima in all seasons, more pronounced in summer and spring.

Regarding the seasonal average temperature, it is observed that during winter temperatures go from slightly negative values (−1°C) to almost 0°C in the recent period. Spring shows stability until 1990, then increases to ≈10°C. In summer, a slight decrease is observed (1961–1990), followed by an increase in the period 1991–2023. In autumn, average temperatures increase and the season becomes warmer and longer.

Minimum temperatures (Fig.2) increased in all seasons, most notably in summer and autumn. In winter, minimum temperatures increased, reducing the frequency of cold extremes. This is due to a more pronounced warming of the nights.

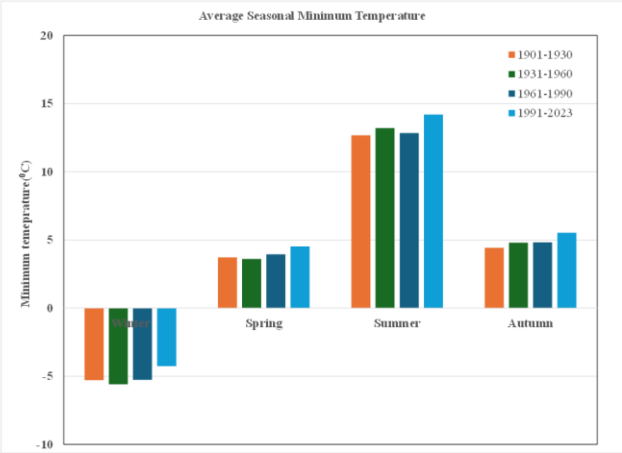


Fig. 2. The dynamics of the average seasonal minimum

The seasonal structure in terms of rainfall (Fig.3) remains the same (wettest summer, driest winter). There are seasonal redistributions: springs and autumns tend to be slightly wetter in the last interval, and summers are slightly less wet than at the beginning of the century.

Basically, the emphasis has shifted slightly from summer to the transitional seasons (spring/autumn), with winters almost unchanged.

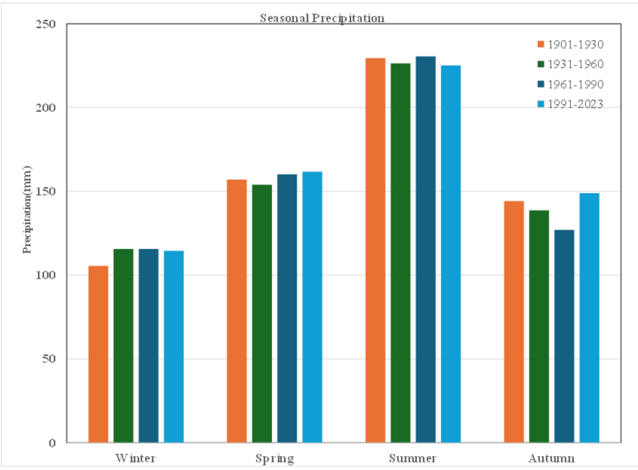


Fig. 3. The Evolution of seasonal precipitation

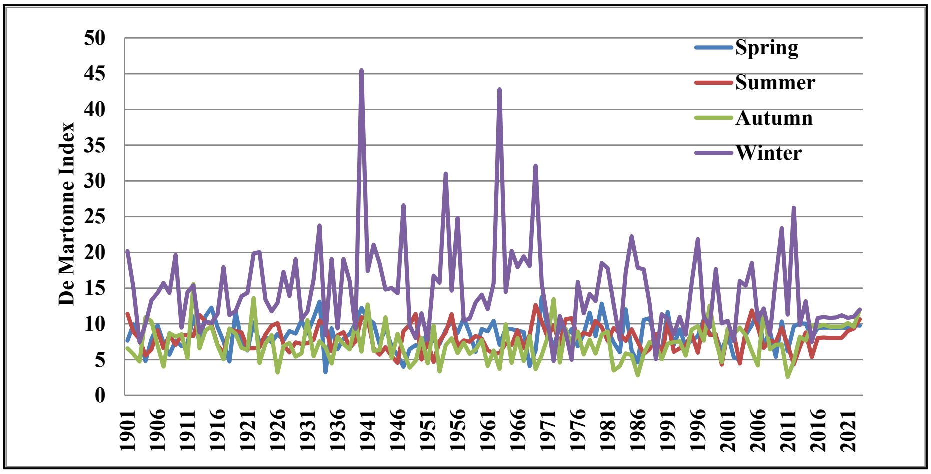


Fig. 4. The dynamics of the seasonal De Martonne Index

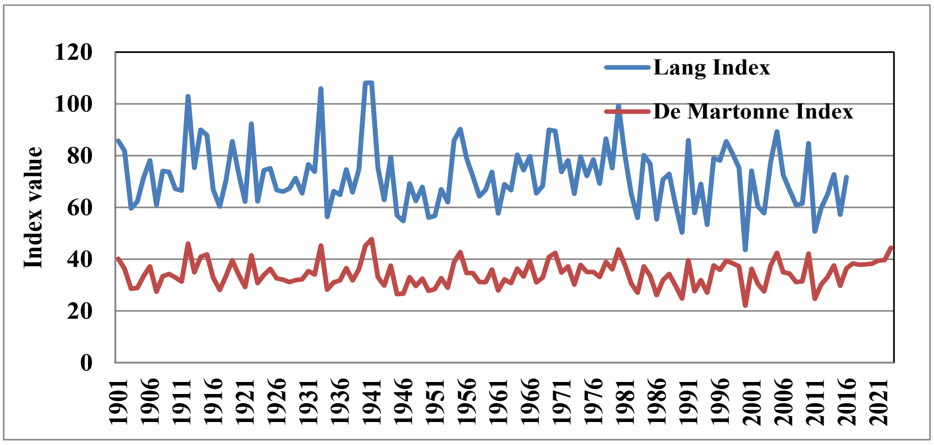


Fig. 5. Comparison: Lang Index vs. De Martonne

Most annual values of the De Martonne Index (Fig. 4) are found between the values 30 and 45, which places Romania in the humid climate zone. Extreme drought years with index values below 30: 1946, 2000, 2012, 2015.

Years with excess precipitation having indices above 45-50 are the following: 1912, 1970, 2005. A slight decrease in the index has been observed in recent decades, signaling a possible increase in aridity.

Both the De Martonne and Lang indices (Fig. 5) show a slight decrease over time, indicating a trend towards increasing aridity. The Lang index has higher values and is more fluctuating, especially in cold years, for example, during severe winters in the first part of the 20th century.

After verifying the homogeneity of variances (Levene) and the normality of the residuals, the ANOVA test was applied for both seasonal precipitation (Table 1) and temperatures (Table 2).

Table 1. Anova Test for seasonal precipitation

Season	F	p-Value	Statistical significance
Winter	0.87	0.457	There are no statistically significant differences
Spring	0.33	0.805	
Summer	0.07	0.977	
Autumn	1.96	0.124	

Table 2. Anova Test for seasonal temperatures

Season	F	p-Value	Statistical significance
Winter	2.04	0.113	No
Spring	3.43	0.020	Yes
Summer	21.18	0	Yes
Autumn	1.33	0.268	No

From Table 2 it turns out that there is a statistically significant difference between average spring and summer temperatures in the 4 analyzed periods (1901–1930, 1931–1960, 1961–1990, 1991–2023). No statistically significant differences were identified in the average seasonal rainfall amounts between the 4 periods analyzed (Table 1). Long-term trends in temperature and precipitation for the period 1901–2023 were analyzed using the nonparametric Mann–Kendall test, applied to seasonal (Table 3) and annual series (Table 4).

Table 3. The Mann-Kendall test for seasonal (temperatures and rainfall) trends (1901–2023)

Season	Temperature				Rainfall			
	Trend	Z	p-Value	Statistical significance	Trend	Z	p-Value	Statistical significance
Winter	Upward	2.22	0.026	Yes	Upward	1.31	0.192	No
Spring	Upward	2.61	0.009	Yes	Upward	0.99	0.324	No
Summer	Upward	3.31	0.0009	Yes	Downward	-0.11	0.911	No
Autumn	Upward	1.43	0.152	No	Upward	0.41	0.68	No

Table 4. The Mann-Kendall test for annual (temperatures and rainfall) trends (1901–2023)

Parameter	Trend	Z	p-Value	Statistical significance
Temperature	Upward	3.9	9.8e-05	Yes
Rainfall	Upward	0.61	0.54	No

The average annual temperature over the period 1901–2023 shows a statistically significant increase, while the slight increase in annual precipitation did not prove statistically significant.

Table 5. Coefficient of Variation (CV) of seasonal precipitation (1901–2023)

Season	CV (%)	Statistical significance
Winter	26.16%	high variability
Spring	22.64%	high variability
Summer	21.09%	moderate-high variability
Autumn	31.17%	the greatest variability

From the values of the coefficient of variation (Table 5) it is observed that precipitation is much more variable between years in seasons than throughout the year. Autumn and winter are the most unstable seasons in terms of precipitation amounts, with frequent variations between dry and rainy years.

Table 6. Coefficient of variation (CV) of seasonal temperatures (1901–2023)

Season	CV (%)	Statistical significance
Winter	-97.65%	invalid value because the average is ~ 0^0C
Spring	12.09%	moderate variability
Summer	4.84%	low variability
Autumn	11.72%	moderate variability

From the coefficient of variation values for seasonal temperatures (Table 6) it can be seen that winter has the highest absolute variability (in ^{0}C), but the CV cannot represent it correctly due to the mean close to zero.

Figure 6 shows the projections calculated for Romania in average annual temperatures for until 2100 according to the RCP 2.6 and RCP8.5 scenarios.

The RCP 2.6 scenario represents a low-emissions scenario and aims to limit global warming to around 2°C by 2100. RCP 8.5 assumes much higher emissions and implies a much greater global warming of around 4.8°C by 2100.

The graph in Figure 6 illustrates the projected evolution of annual mean temperature anomalies for Romania, under two emission trajectories. The vertical axis represents the temperature increase **(°C)** compared to a reference period. The curves represent the RCP 2.6 (low emissions) and RCP 8.5 (high emissions) scenarios [5,8]. In both scenarios, the warming signal is monotonically increasing throughout the represented range. Between 2025 and ~2050, the fastest increase is observed, followed by a moderation of the slope after mid-century. In RCP 2.6, the anomaly passes ~1 °C around 2030, reaching ~3.5°C by 2070. In RCP 8.5, the thresholds are exceeded earlier and at higher levels: ~1.1°C in 2030, with an increase to ~5°C in 2070. The projections difference progressively widens, highlighting the decisive role of the emissions trajectory on the future climate. The quantitative interpretation of the graph depends on the choice of the climatological reference period and the processing methods. The variability of the climate system may induce long-term deviations around the presented projections. These projections conclude that warming is inevitable in the coming decades.

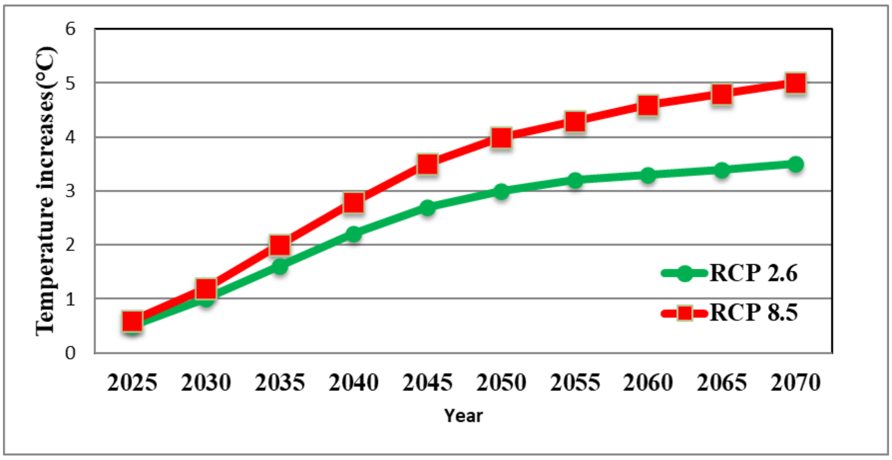


Fig. 6. Projections of increases in average annual temperatures for Romania until 2100 according to the RCP 2.6 and RCP8.5 scenarios

4. CONCLUSIONS

The Mann-Kendall test indicates that the average annual temperature during the period 1901–2023 shows a clear and statistically significant increase. This confirms the trend of global warming at the local level in the analyzed data. The De Martonne indices show a weak decreasing trend, suggesting a slow increase in the aridity of the Romanian climate: De Martonne: −0.0091/year, Lang: −0.0045 to −0.0157/year.

There is a significant warming trend in all seasons except autumn (statistically insignificant growth) according to the Mann-Kendall test. There is a slight increase both in annual and seasonal precipitation, but it is not statistically significant.

Continuous monitoring and inclusion of this information in climate adaptation strategies are crucial.

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