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COMPARISON OF MULTIANUAL CLIMATIC DATA IN NORTH BUCHAREST REGION, ROMANIA

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Abstract

Temperature, precipitation, and light are essential climatic parameters for fruit tree life and productivity, and they have a consistent and specific influence on each plant's growing stage. Considering the whole ecosystem, strong linkages between those parameters are highlighted. The present study analyzes multiannual climatic data (over 50 years) regarding precipitation and solar radiation at the International Meteorological Station Bucharest-Băneasa, Romania. A comparative synthesis between months and a correlation between the two parameters is presented. The study results are essential for understanding the area's climate changes more closely and for incorporating them into future strategies for orchard management.

Key words: *weather station, sensors, automation, irrigation.*

INTRODUCTION

Understanding how precipitation and surface solar radiation (SSR) have co-evolved in recent decades is important to diagnosing changes in regional hydroclimate and anticipating water-, energy-, and horticulture-related risks. The latest IPCC assessment concludes that the global hydrological cycle is intensifying, with heavy precipitation events increasing in frequency and intensity in many regions, consistent with thermodynamic scaling of atmospheric moisture (IPCC, 2021a, 2021b). Large multi-dataset studies also report widespread increases in extreme rainfall, including global analyses of annual maximum daily precipitation and the largest events in each record, while acknowledging spatial heterogeneity and methodological sensitivity (Fischer & Knutti, 2015; Papalexiou & Montanari, 2019; Westra et al., 2013). Observational syntheses further show that the intensification signal is now evident in the measured record, broadly consistent with theory and model projections (Fischer & Knutti, 2015; IPCC, 2021b; Papalexiou & Montanari, 2019; Westra et al., 2013).

Against this hydrological backdrop, the surface radiation budget has undergone pronounced multi-decadal changes known as “global dimming” (roughly the 1950s–1980s decline in SSR) followed by “global brightening” since the mid-1980s, linked to aerosol emissions, air-quality regulation, and cloud changes (Wild, 2009, 2012). Over Europe, high-quality satellite and surface datasets show a continent-wide SSR increase since the 1980s (about +1.9 to +2.4 W/m² per decade), with decadal variability and good agreement with homogenized sunshine-duration records; newer records (e.g., SARAH-3) provide consistent, long, quality-controlled series (Pfeifroth et al., 2018; Pfeifroth et al., 2024; Sánchez-Lorenzo et al., 2017). Recent analyses have further examined the causes of European brightening, highlighting the roles of aerosol reductions and cloud changes (Pfeifroth et al., 2018; Sánchez-Lorenzo et al., 2017; Wild, 2012).

The physical linkages between radiation and precipitation operate on multiple scales. At daily scales, cloudiness produces a strong negative correlation (low SSR on rainy days). In contrast, at monthly scales, co-seasonality can yield weak

positive associations in convective seasons - even as SSR and rainfall are not causally related per se. These interactions are embedded in the broader aerosol-cloud-precipitation system, where anthropogenic aerosols alter radiation directly and modify cloud microphysics and precipitation efficiency (IPCC, 2021a; Ramanathan et al., 2001a, 2001b). IPCC provides an authoritative synthesis of these aerosol-radiation-cloud interactions and their effective radiative forcing; detailed reviews and field campaigns (e.g., INDOEX) have quantified how aerosol loading can reduce SSR by ~10% seasonally and suppress precipitation in specific regimes (Ramanathan et al., 2001a, 2001b).
At regional scales in Eastern Europe, studies report significant spatial and temporal variability in precipitation trends and extremes. Several analyses have found significant changes in daily extreme indices over the post-1960 period at some stations, alongside mixed signals in totals. This underscores the need for long, homogenized local records to resolve decadal variability versus trend (Busuioc et al., 2017; Croitoru et al., 2016)
Despite substantial progress, three issues remain particularly pertinent at regional and country scales: (i) the joint evolution of SSR and precipitation has rarely been assessed using co-located, multi-decadal observations; (ii) potential regime shifts (e.g., post-1980s brightening) may alter the seasonal distribution and variability of rainfall without significant changes in annual means; and (iii) the scale dependence of radiation-precipitation relationships (daily vs. monthly vs. annual) is often overlooked in detection-and-attribution studies. By leveraging century-long precipitation records (1895-2024) and SSR measurements (since 1964), our analysis addresses these gaps, quantifying trends, variability, and timescale-dependent co-variability within a consistent observational framework, and situating local findings within the robust global context summarized.

MATERIALS AND METHODS

The Bucharest-Băneasa International Weather Station data for 1895-2024 for precipitation and 1964-2024 for solar radiation were analyzed (Ecad.eu, 2025).
Bucharest-Băneasa Weather Station is placed at the extremity of the city, at 4.3 km from the Agronomie - Herastrau University campus, in the North-West part of Bucharest city (44º28'12", 26º03'51", 86 m altitude).
Statistical analysis was performed with the R program (with RStudio 2024.04.2+764).

RESULTS AND DISCUSSIONS

Trends and dynamics in precipitation at Bucharest-Băneasa International Station

Annual and monthly precipitation quantities were compared from 1895 to 2024 (Figures 1-3).

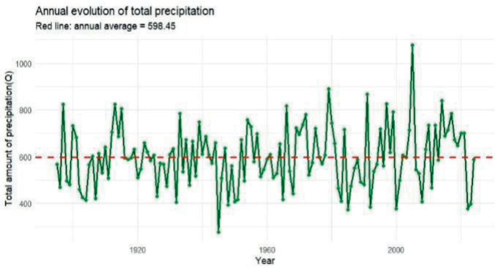

Figure 1. Annual evolution of total precipitation in the 1895-2024 period

Total precipitation has been highly variable with alternating wet and dry periods rather than an apparent long-term increase or decrease.
They can be identified as multi-year clusters: (1) drier spells: late 1920s-1930s, mid-1940s, and several years in the early 2010s and early 2020s fall below the mean (598.45 mm); (2) wetter spells: mid-1910s and especially the late 1990s-2000s show a run of above-average totals, including some of the highest peaks.
The amplitude of extremes appears larger after ~1970, with more frequent very wet years alongside some deep minima, suggesting increased variability in recent decades.
In Figure 2, there appear to be more frequent very wet months, especially in parts of the 1990s-2000s, alongside strings of dry months, suggesting higher variability rather than a steady trend.

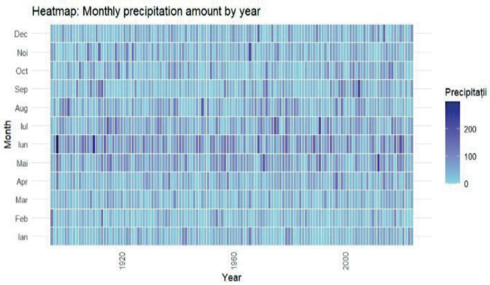

Figure 2. Heat map with monthly precipitation amounts by year

A detailed analysis is presented for each month in Figure 3. In January, generally modest totals and relatively small year-to-year differences. There are occasional wet spikes, but long dry runs appear mid-century. There was no apparent long-term trend observed. February is typically the driest month. There are frequent low precipitation amounts. Variability is low to moderate and trendless. March is a transitional month, with totals and variability increasing compared to winter. There is an alternation of wet/dry years without an apparent directional change. April marks a further step up from March. Mixed conditions are present: some dry periods punctuated by wet events. No clear trend was observed; moderate variability is presented. May is the start of the convective season. A marked increase in variability with several very wet Mays is observed. In recent decades, wet outliers seem more frequent. June is among the wettest months, with extensive interannual periods of multiple high peaks (convective storms). Post-1970 variance looks higher. July is still in the seasonal maximum, with repeated very wet Julys interspersed with very dry periods. The variability is high and the mean level broadly stable. August presents high levels, but they taper slightly from July. Significant year-to-year differences continue, and some prolonged dry runs are offset by intense wet years. September is the transition toward autumn rains. The total precipitation amounts remain relatively high. There were identified clusters of wet Septembers, particularly in the late 20th/early 21st centuries. October is the month when the autumn maximum begins. There are many wet Octobers, including some of the most significant monthly totals in the record. The variability is high. November is often part of the autumn peak. There are several very wet Novembers and multi-year wet clusters. Interannual variance is comparable to summer high-variability months. December returns toward winter levels. The totals and variability are lower than in October and November. During the analyzed period, there were occasional wet Decembers, but no clear trend.

Comparing the monthly precipitation amounts, the wettest season is a bimodal pattern - summer (May-August, especially June-July) due to convective rains, and autumn (October-November) due to frontal systems.

The driest months are February and, to a lesser extent, January and December.

The highest variability is presented in June-August and October-November (frequent extremes). The lowest variability occurs in January and February.

Regarding temporal changes, they are no strong, consistent trend in the mean apparent for individual months, but several months, especially June–July and October-November, show more frequent extreme wet months in the late 20th and early 21st centuries (i.e., increased variability rather than a steady rise or fall in averages).

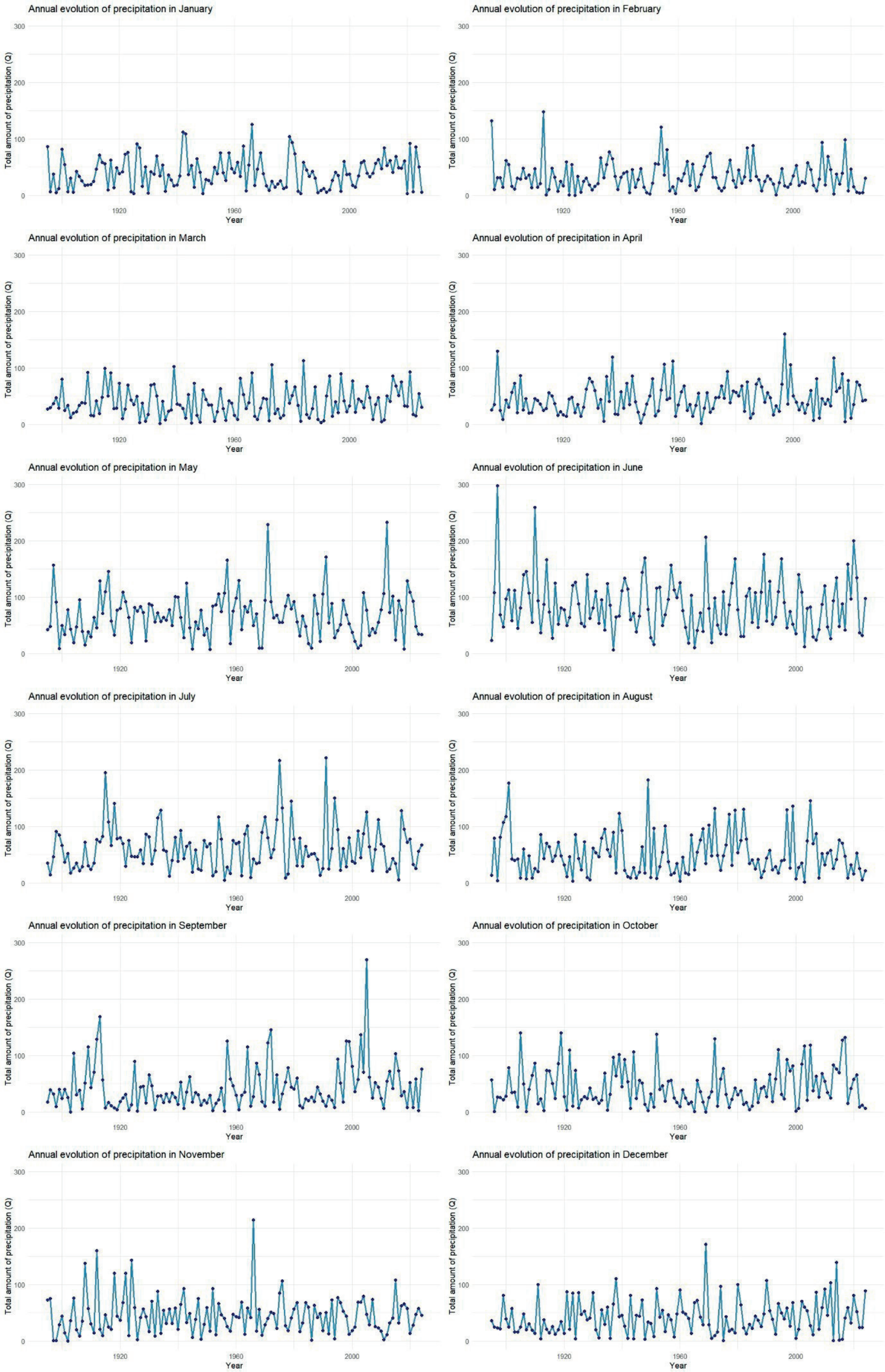

Figure 3. Monthly mean precipitation amounts (1895-2024)

Comparing the 2000-2024 period with the 1895-2024 period, the annual precipitation average increases by 5.8%, from 598.2 mm/year to 633 mm/year. Analyzing each month, it can be observed the following: January +6.7 mm (+16.7%), February −0.9 mm (−2.7%), March +4.7 mm (+12.2%), April +0.7 mm (+1.5%), May: +0.3 mm (+0.4%), June −3.9 mm (−4.6%), July −0.9 mm (−1.5%), August −5.9 mm (−11.7%), September +15.3 mm (+35.7%) – being the most significant increase, October +12.2 mm (+27.7%), November −1.3 mm (−2.9%), and December +7.8 mm (+18.5%). Since 2000, the totals are higher overall, driven mainly by much wetter September-October and wetter mid-winter (Dec–Jan). The summer (June-August) is drier, especially in August. This points to a shift of precipitation toward autumn and winter.

Trends and dynamics in solar radiation at Bucharest-Băneasa International Station

Annual and monthly solar radiation values (W/mp^2) were compared for the period 1964 to 2024 (Figures 4-6).

When analyzing the multiannual variation of the solar radiation (Figure 4), no strong monotonic trend across the whole period is observed; instead, a regime change occurs from dimmer conditions pre-mid-1980s to brighter and more variable conditions afterward.

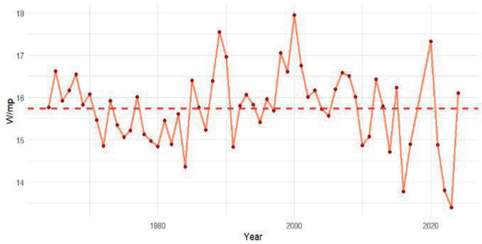

Figure 4. Annual evolution of total solar radiation in the 1964-2024 period

Comparing monthly values (Figures 5 and 6), there is a seasonal cycle: radiation climbs from December/January minima to a June-July plateau (the annual peak), then declines through autumn. The highest months are June and July with maximum energy availability. The lowest months are December, January, and then November/February.

Regarding variability, the summer months (June-August) exhibit the tightest year-to-year range, while the transition months (March-April, September) are slightly more variable. Low and steady values characterize winter.

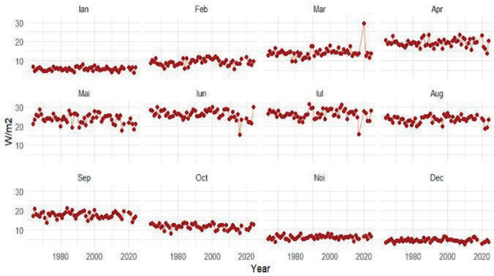

Figure 5. Monthly average solar radiation trends by year (1964-2024)

January has low winter values (~9-11 W/mp^2) and presents a small interannual spread. February is slightly higher than January (~10-12 W/m^2) with modest scatter. March increases to ~13-16 W/m^2. April has an average of ~16-19 W/m^2. May goes to ~20-23 W/m^2. June has the near-annual maximum (~23-26 W/m^2), being very stable with rare dips. July is similar to ~24-27 W/m^2. August starts the late-summer decline (~22-25 W/m^2). September presents an average of ~18-21 W/m^2. October has ~13-16 W/m^2. November is back to winter-like levels, ~10-12 W/m^2. December had the annual minimum (~8-10 W/m^2).

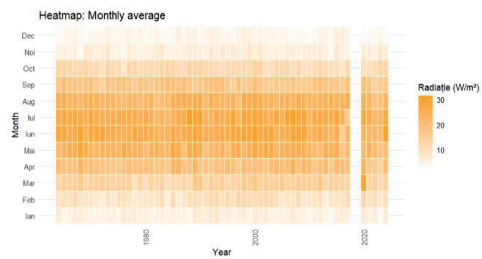

Figure 6. Heatmap - monthly solar radiation amounts by year

Comparing the 2000-2024 period with the 1964-2024 period, the annual solar radiation remains remarkably stable over decades, without significant differences. The main small changes are a brighter March and slightly dimmer October through December. For planning, the most reliable high-radiation window remains

June-July; early spring has improved marginally, while late autumn-early winter is weaker. Month-by-month changes (2000–2024 vs. 1964-2024) in W/mp^2 are January −0.04 (−0.7%), February +0.08 (+0.9%), March +0.80 (+5.6%) being the most significant increase, April +0.20 (+1.0%), May −0.30 (−1.3%), June −0.70 (−2.7%), July +0.20 (+0.8%), August +0.20 (+0.9%), September −0.40 (−2.3%), October −0.40 (−3.4%), November −0.01 (−0.2%), and December −0.19 (−4.3%), being the most significant decrease.

Correlation between precipitation and solar radiation at Bucharest-Băneasa International Station

Regarding the correlation between annual values for solar radiation and precipitation, there is a clear but weak inverse tendency: brighter years are generally drier, but many other factors drive precipitation. Hence, solar radiation is not a reliable predictor of annual rainfall in a standalone capacity. No significant correlation was observed between them (Figures 7-9).

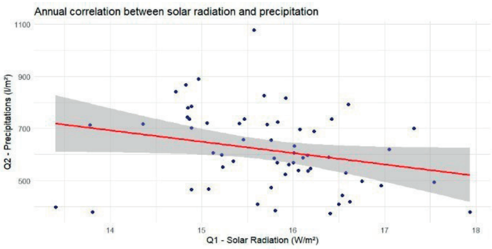

Figure 7. Annual correlation between solar radiation and precipitation

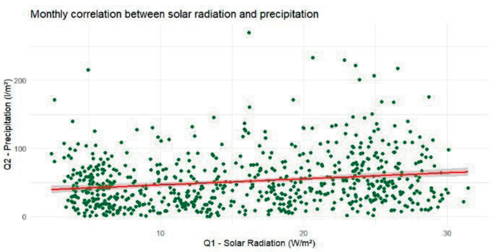

Figure 8. Monthly correlation between solar radiation and precipitation

Our station-based analysis provides a coherent image of how precipitation and surface solar radiation (SSR) have co-varied locally over the last 6-12 decades, and how these results sit within the broader literature. Since 2000, the annual total precipitation increased from ~598 to ~633 mm/year (+5.8%).

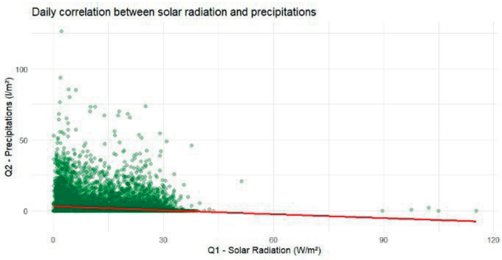

Figure 9. Daily correlation between solar radiation and precipitation

However, the signal is strongly seasonal: autumn rose the most (+19.8%, driven by September +35.7% and October +27.7%), winter also increased (+11.8%, mainly December +18.5% and January +16.7%). The long record shows significant year-to-year variability and an apparent increase in the amplitude of wet and dry years after \~1970, rather than a persistent monotonic trend. This pattern aligns with the intensification of the hydrological cycle and the rising heavy-precipitation potential assessed in the IPCC AR6, while also reflecting the firm regional heterogeneity emphasized therein (IPCC, 2021a, 2021b). It is consistent with European and Eastern European findings of mixed changes in totals but more frequent/stronger extremes at many sites (Busuioc et al., 2017; Croitoru et al., 2016; Fischer & Knutti, 2015; Papalexiou & Montanari, 2019; Westra et al., 2013).

The monthly SSR climatology retains a stable seasonal cycle (minima in December–January, maxima in June-July). The full-time series exhibits the classic pre-mid-1980s “dimming” followed by “brightening” regime change, which has been documented globally and across Europe, and is linked to aerosols and cloudiness (Wild, 2009, 2012; Pfeifroth et al., 2018, 2024; Sánchez-Lorenzo et al., 2017). Our slight autumn dimming coincides with the increase in autumn precipitation, a physically self-consistent pairing (more cloudiness, less SSR).

At the daily scale, a negative correlation was found to be non-significant, following the normal trend: rainy days cluster at low SSR, and high-SSR days are almost always dry. At the monthly scale, the slope turns weakly positive, reflecting co-seasonality (bright months coincide with the convective season that can produce rainfall). At the annual scale, the relationship reverts to a weak negative association.

This scale dependence is expected from basic radiative-cloud physics and from the aerosol-cloud-precipitation interactions synthesized by IPCC and classic field studies (IPCC, 2021a; Ramanathan et al., 2001a, 2001b): clouds both reduce SSR and enable precipitation, while aerosols can dim SSR directly and modify cloud microphysics and rain efficiency.

CONCLUSIONS

The local hydro-radiative system shows seasonally reallocated wetting and largely stable radiation with subtle autumn dimming, changes that are physically consistent and literature-congruent, and that matter operationally for water, farming, and energy planning. Mean annual precipitation increased by ~6% in the 2000-2024 period versus the historical baseline, but the rise is not uniform: it is concentrated in autumn (most significant gains in September and October) and mid-winter (December-January), while summer totals declined slightly (especially August).

Radiation is stable, mainly with seasonal nuances. The SSR seasonal cycle (minima December-January, maxima June-July) is stable. Recent decades show minor, month-scale adjustments, a brighter March and a slightly dimmer October-December, superimposed on the well-known dimming-brightening regime change since the mid-1980s. For water management, greater cool-season inputs and more frequent wet autumns require monitoring of flood-prone windows. Irrigation stress may intensify in summer despite stable summer radiation, with the leverage of autumn-winter recharge.

ACKNOWLEDGEMENTS

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