ASSESSMENT OF PRECIPITATION TRENDS IN THE BÂRZAVA CATCHMENT, ROMANIA

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Abstract. Climate change challenges the stationarity assumption which is the base for the traditional hydraulic infrastructure design. This leads to the need to perform analyses of precipitation and temperature trends. This study examines long-term hydro-climatic changes in the Bârzava River basin, western Romania, a flood-prone catchment with cascade reservoir systems, that is critical for flood protection. Using mean monthly precipitation, along with maximum and minimum temperature data from eight meteorological stations spanning 1960–2021, we applied the Mann-Kendall test and Sen's slope estimator to detect monotonic trends, complemented by Inverse Distance Weighting interpolation to assess spatial variability across the 1,190 km^2 catchment. Results reveal upward trends in monthly precipitation, with the strongest increases during June-August (Kendall's τ up to 0.46, Sen's slopes 0.05–0.07 per year) and additional significant increases from January through May and in December. September-November months showed no detectable trends, indicating non-uniform seasonal changes. Spatial patterns confirm highest precipitation in the Semenic Mountains and lowest in the plains, with June consistently recording peak monthly totals. These findings demonstrate that climate change altered intra-annual distribution rather than uniform annual increases, with implications for intensified warm-season flood risk and potential low-flow stress.

Key words: precipitation trends, Mann-Kendall test, Bârzava River basin

1. INTRODUCTION

For decades, engineers, hydrologists, and water resource managers have designed hydraulic structures, planned urban drainage systems and developed water supply strategies based on the fundamental assumption of stationarity, the principle that historical precipitation patterns and statistical properties remain constant over time. This approach led to design standards such as the Romanian norms for hydrotechnical structures (Ordinul Arhitecților din România, 2021) or the Romanian standard PD 95-2002 for hydraulic design of bridges and culverts. The later has guided the design of critical infrastructure including dams, spillways, bridges, culverts, and urban stormwater management systems. Design standards have typically relied on Intensity-Duration-Frequency (IDF) curves derived from historical precipitation records, with infrastructure dimensioned based on return period analyses of past events. However, ongoing climate change has challenged and altered this paradigm, showing that historical data is more and more unreliable as predictor of future conditions (Martel *et al.*, 2021; Schlef *et al.*, 2023). Changes in precipitation and temperature trends are closely linked to climate change, with human-induced land-use change, including deforestation, urbanization, and agricultural intensification serving as additional factors that influences local and regional climate conditions. Rising global temperatures significantly disrupt the water cycle (Calvin *et al.*, 2023) by altering precipitation patterns, affecting freshwater availability and distribution, and intensifying the frequency and magnitude of extreme events such as droughts and floods across various regions of the world. These shifts pose challenges to existing water management infrastructure and practices, requiring updated analyses that can support adaptive strategies (Jonoski *et al.*, 2025), as well as new ways of checking structures safety (Popescu *et al.*, 2024).

An increase in global average temperature leads to an increased capacity of the atmosphere to hold water vapor, following the Clausius-Clapeyron relationship, which indicates approximately a 7% increase in atmospheric moisture content per degree Celsius of warming (Westra *et al.*, 2014). As air temperature increases, this enhanced atmospheric water vapor content can lead to more intense precipitation events, even in regions where total annual precipitation may decrease. This phenomenon led to the situation where some regions experience both intensified extreme rainfall events and prolonged dry periods. The frequency and intensity of heavy rainfall events have increased both at national and global scales (Masson-Delmotte *et al.*, 2021), with climate change identified as the primary determining factor driving these changes. The evidence for this includes observational data, climate model projections, and physical understanding of atmospheric processes.

The increasing trend in extreme precipitation across Europe has been analyzed in numerous studies, which have concluded that a general intensification of extreme events can be observed, *particularly in short-duration, high-intensity precipitation events* (Tank and Können, 2003; Sun *et al.*, 2021). Furthermore, the relationship between seasonal temperatures and precipitation has become an increasingly important research topic, with studies such as Lhotka and Kyselý (2022) examining the correlation at the European scale and revealing complex spatial and temporal patterns in how warming affects precipitation regimes across different seasons and geographical contexts.

In recent decades, the Eastern European region, including Romania, has experienced climate changes influenced by both global warming trends and regional factors such as land-use changes and urbanization. Recorded meteorological data and comprehensive regional climate assessments reveal a considerable and accelerating increase in average annual temperatures throughout Eastern Europe, with most monitoring stations having recorded a warming rate exceeding 1.0°C since 1960, and some locations experiencing increases approaching or exceeding 2.0°C (WMO, 2025). Concurrently with these temperature changes, researchers have documented significant alterations in precipitation patterns, including an increase in the magnitude, frequency, and probability of extreme precipitation events across regions (Sen Roy and Balling Jr., 2004; Bengtsson and Rana, 2013). These changes are not uniform; rather, they show spatial and temporal variability, with some areas experiencing increases in extreme precipitation while others face declining trends in total precipitation or shifts in seasonal distribution. Extreme precipitation events trigger important hydrological consequences on local or regional scales, including riverine floods, flash floods in small catchments, urban flooding due to overwhelmed drainage systems, and periods of meteorological and hydrological drought, all of which have social and economic impacts. These impacts include loss of life and property, agricultural losses, disruption of transportation and economic activities, contamination of water supplies, and displacement of populations. Along with the increased flooding risk documented for most parts of Europe, an increase in the frequency and severity of meteorological drought has been detected since 1950 in southern Europe and most of central Europe, while in many parts of northern Europe, the frequency of drought has decreased, highlighting the spatially heterogeneous nature of climate change impacts (Spioni *et al.*, 2017)

Given these rapidly changing climatic conditions, updated and comprehensive precipitation analyses are critical for operational water management systems, particularly in basins with significant infrastructure and population exposure to flood risk.

The Bârzava River basin in the Banat region of western Romania presents is an important case study for such analysis due to its unique combination of hydrological characteristics, existing infrastructure, and flood vulnerability (Herbei *et al.*, 2024). The Bârzava basin represents one of the most flood-prone areas in the Banat region, with a documented history of damaging flood events that have caused significant property damage and threatened public safety. In the upper reaches of the Bârzava River, three reservoirs are located in cascade configuration, a system design where the outflow from one reservoir becomes the inflow to the next downstream reservoir. These reservoirs serve multiple critical and sometimes competing functions: satisfying various downstream water demands including municipal water supply, industrial uses, and agricultural irrigation; attenuating flood waves by temporarily storing excess runoff during extreme precipitation events and providing flood protection for downstream communities and agricultural areas. The effective operation of such multi-purpose cascade reservoir systems requires understanding of inflow patterns, which in turn depends on accurate characterization of precipitation patterns and trends in the upstream catchment. Effective operation of the cascade reservoir system including decisions about reservoir storage levels, release rates, and flood control rules and adequate protection of downstream populations require hydrological models based on updated precipitation data that reflect current and projected future climate conditions rather than outdated assumptions based on historical stationarity (Hassaballah *et al.*, 2012; Samadi *et al.*, 2025)

This research addresses a critical knowledge gap in the scientific understanding of precipitation changes in western Romania. Although the importance of precipitation trend analysis has been investigated in various regions of Romania through previous studies (Croitoru *et al.*, 2012). While national-scale assessments have identified general patterns of change, no studies have addressed the spatial and temporal variability of precipitation trends within the Bârzava basin, despite its status as one of the main river basins in western Romania and its significant importance for regional water security and flood risk management. This gap in knowledge limits the ability of water resource managers and civil protection authorities to take informed decisions about reservoir management, flood warning systems, and long-term infrastructure planning.

The primary objective of this paper is to analyze long-term trends in precipitation and temperature time series for the Bârzava basin, providing essential quantitative insights for evidence-based water resources management and climate adaptation planning. Catchment permeability and antecedent hydrological conditions including soil moisture status, snowpack, and initial reservoir levels (Fortesa *et al.*, 2020) – can significantly influence the spatio-temporal relationship between precipitation and runoff generation, making it important to understand not only precipitation trends but also how these trends interact with catchment characteristics. The detailed analysis of precipitation and temperature trends and extremes can provide improved scientific basis for protecting against future flood risk in the Bârzava River basin, support more effective and adaptive operation of the cascade reservoir system under changing climatic conditions, and contribute to regional climate change adaptation strategies in western Romania.

2. METHODOLOGY

The main aim of the study was threefold:

- To analyze trends in maximum and minimum temperature over the Bârzava catchment.
- To analyze mean monthly precipitation using Mann-Kendall test and Sen's slope estimator/
- To evaluate the spatial distribution of mean precipitation, through geostatistical interpolation approach.

Non-parametric trend analysis offers a reliable methodological approach to analyze the rainfall over Bârzava catchment, because it does not require normally distributed data and it is robust to outliers, making it well suited for hydrological time series. Therefore, the Mann-Kendall (MK) test was selected to detect monotonic trends in precipitation and temperature, as it is widely used for identifying directional changes in hydro-climatic variables (Liebscher, 2021). The analysis was applied to continuous precipitation time series, structured as monthly totals obtained from meteorological and hydrological stations across the basin. Prior to computation, datasets were evaluated for completeness, consistency, and potential serial correlation to ensure the validity of the MK test. Once the presence of a trend was established, Sen's slope estimator was used to determine its magnitude and rate of change. Together, these techniques provide a comprehensive evaluation of how precipitation patterns evolve over time, highlighting shifts in rainfall intensity, distribution, and seasonality that are relevant for hydrological modelling and climate adaptation strategies.

2.1. Study Area and data

The Bârzava River (Fig. 1) is a tributary of the Timiș River, located in western Romania, primarily within CaraşSeverin and Timiș counties. The river originates in the Semenic Mountains and flows approximately 166 km before joining the Timiș River. The total drainage area of the catchment is about 1,190 km². The upper basin is characterized by steep, narrow valleys and mountainous terrain, whereas the middle and lower reaches transition into lowmountain, eventually entering the Banat Plain.

The catchment has big variations in altitude, which strongly influences its climate and hydrology. Average annual precipitation ranges from 600 to 1,400 mm (Herbei *et al.*, 2024) increasing with elevation, while multiannual average temperatures range from around 10–11°C in the plains to below 0°C in the higher mountain zones. Climate is temperatecontinental, with clear seasonal variability in both temperature and precipitation. Several tributaries, such as the Văliug, Crivaia Mare, Râul Alb, and Terova, contribute to the Bârzava's flow, and the upper basin contains key reservoirs including Văliug, Gozna and Secu lakes (Bădaluţă-Minda and Herbei, 2022).

Human interventions in the catchment area include riverbed regulation and flood control measures, particularly in the lowland sections. These interventions, along with the basin's complex topography, make the Bârzava catchment a suitable area for studies of spatial and temporal variability in precipitation and temperature.

For the present study, monthly data on maximum and minimum temperatures and mean monthly precipitation for 1960-2021 were collected from eight meteorological stations (Fig.1, Table 1) distributed across the river basin, including its extremities.

The spatial distribution of the stations is uneven, with most stations concentrated in the mountainous areas of the catchment, while some extend into the plains. The spatial variation of average monthly precipitation for the 1960 -2021 period is shown in figure 2, and the corresponding variation in maximum and minimum monthly temperatures is presented in figures 3 and 4, respectively. Average annual precipitation ranges from a minimum of 95 mm in the lowland areas to a maximum of 145 mm in the mountainous regions, specifically in the Semenic Mountains area.

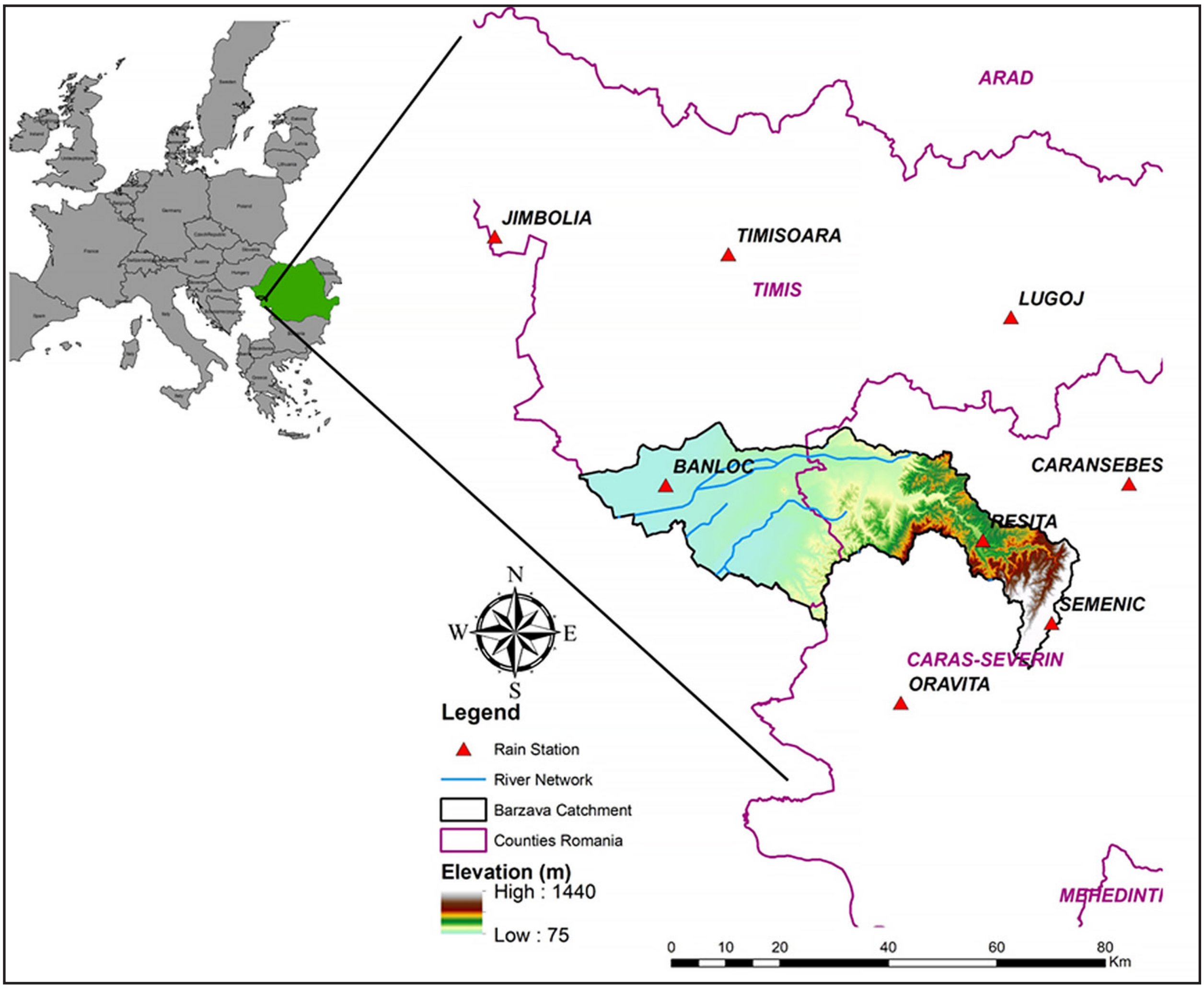

Fig. 1. Barzava river catchment and the location of eight rainfall stations.

Table 1. Rainfall stations location and elevation.

Station name	Latitude	Longitude	Elevation (m)
BANLOC	21.13	45.38	82
CARANSEBES	22.23	45.42	205
JIMBOLIA	20.70	45.78	78
LUGOJ	21.93	45.69	123
ORAVITA	21.71	45.04	302
RESITA	21.89	45.31	253
SEMENIC	22.06	45.18	1423
TIMISOARA	21.25	45.77	91

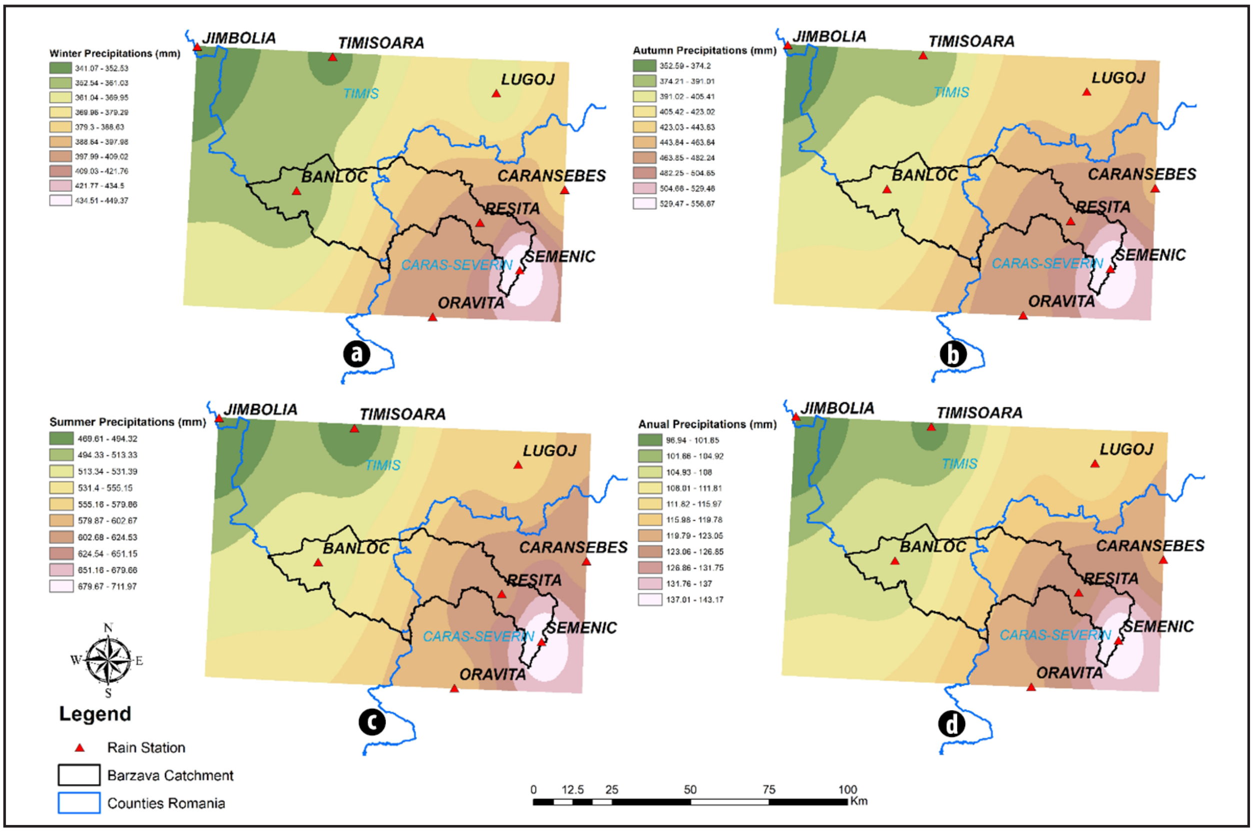

Fig. 2. Mean seasonal and annual rainfall over the catchment area and surrounding regions for the period 1960–2021: (a) winter; (b) autumn; (c) summer; and (d) annual.

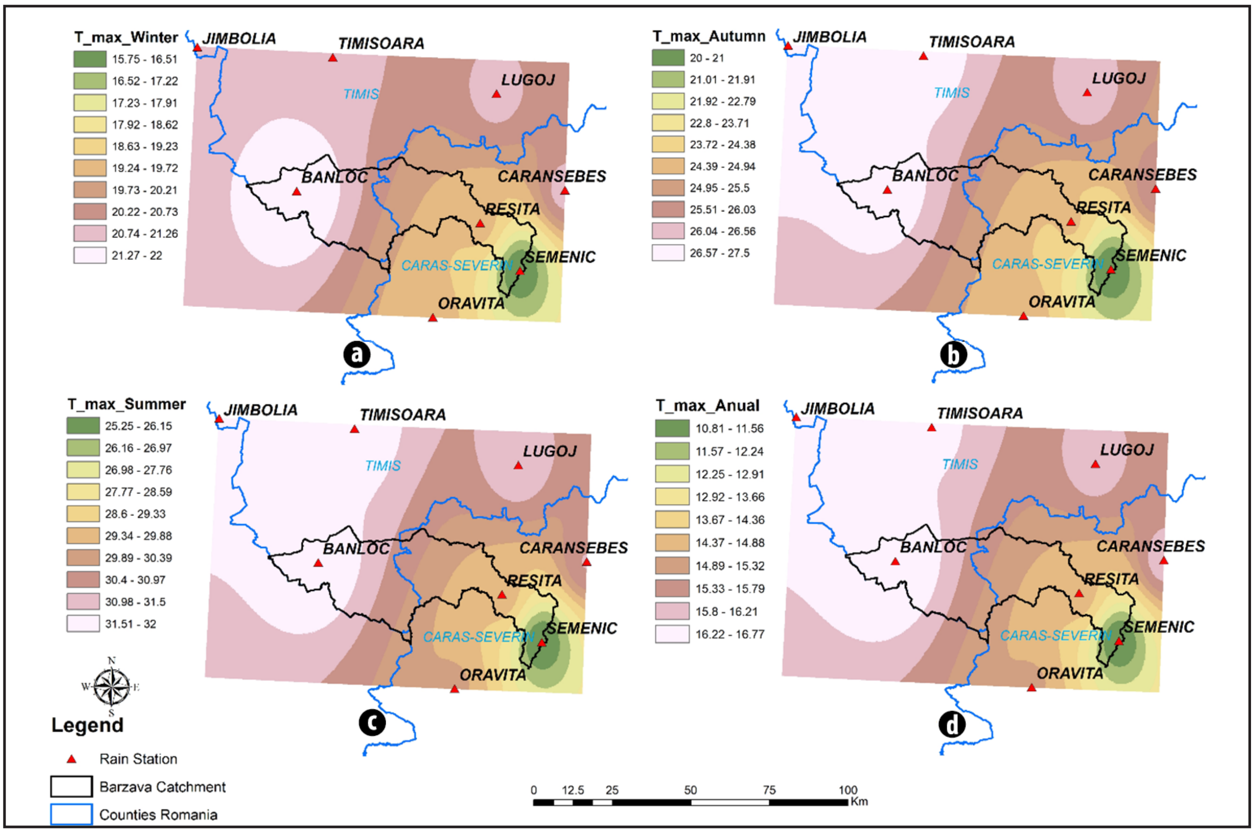

Fig. 3. Maximum temperature climatology during the period 1960–2021 for: (a) winter season; (b) autumn season; (c) summer season; and (d) maximum temperature over the catchment area and surrounding during the period 1960–2021.

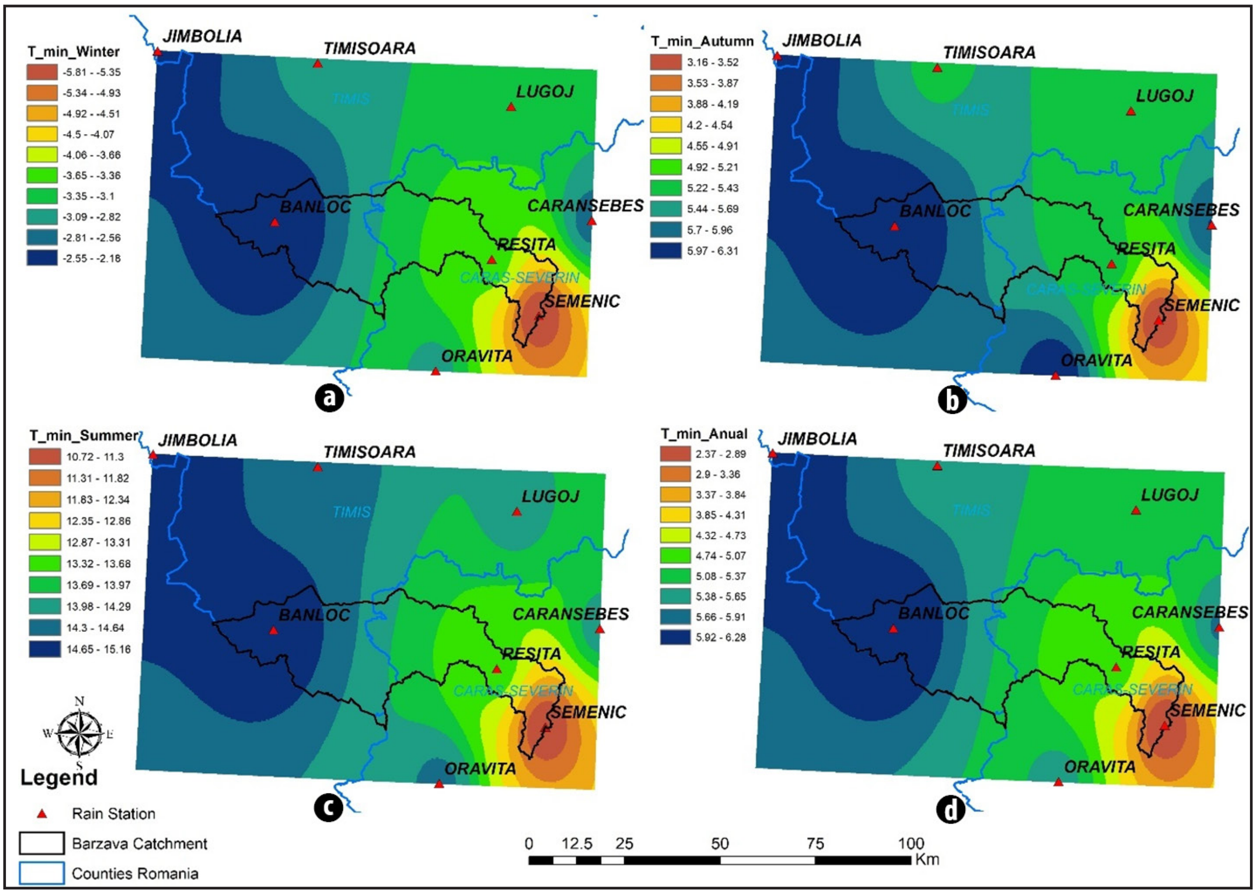

Fig. 4. Minimum temperature climatology during the period 1960–2021 for: (a) winter season; (b) autumn season; (c) summer season; and (d) maximum temperature over the catchment area and surrounding during the period 1960–2021.

Due to the uneven distribution of the eight meteorological stations across the Bârzava River basin the Inverse Distance Weighting (IDW) method was applied to extend the spatial coverage of precipitation and temperature data. Originally developed by the U.S. National Weather Service in 1972, IDW is employed here to interpolate both precipitation and temperature data by estimating values at unsampled locations by weighting nearby stations according to distance, giving greater influence to closer observations. This approach allows the generation of continuous spatial datasets from the 1960-2021 records, capturing the variability across both highland and lowland areas.

Maximum monthly precipitation shows notable spatial and temporal variations. At the Oravița meteorological station (Fig. 5), the month of June consistently has the highest recorded precipitation, followed by July. Seasonal patterns further highlight the spatial differences in precipitation across the study area.

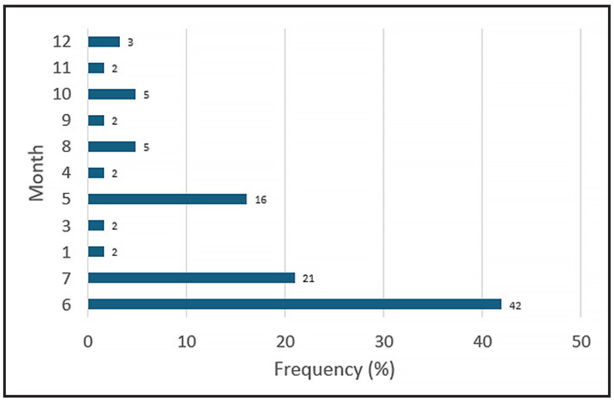

Fig. 5. Relative frequency of maximum monthly precipitation at Oravita station.

2.2. Mann-Kendall test

The Mann-Kendall statistic test *S* is calculated by comparing each data point with all subsequent points in the series and counting the number of increasing and decreasing pairs, as given by equation (1).

$$S=\sum_{1}^{n-1}\left[\sum_{j=i+1}^{n} sgn\left(x_j - x_i\right)\right] \quad (1)$$

where x_j and x_i represent the value of sequence *j* and *i* ($j > i$) which express the time indices associated with individual time series and n is the data length. Moreover:

$sgn(x) = 1$ for $x > 0$

$sgn(x) = 0$ for $x = 0$

$sgn(x) = -1$ for $x < 0$

When the dataset contains tied values (identical measurements), the variance of must be adjusted to account for these ties. Let denote the number of tied values in a group, and the frequency of occurrence of each tied group. The variance of *var*(*S*) is then corrected using these values to ensure the Mann-Kendall statistic follows its expected distribution. This adjustment prevents tied observations from biasing the test and ensures reliable detection of trends.

The variance of *S, var(S)* is given by equation (2):

$$var(S)=\frac{1}{18}\left[n(n-1)(2n+5)-\sum f_t(f_t-1)(2f_t+5)\right] \quad (2)$$

2.3. Sen's Slope Test

Sen's Slope Estimator Test, is used to calculate the magnitude of trends in the long-term temporal data (Rosmann *et al.*, 2016). Unlike significance tests, which only indicate whether a trend exists, Sen's slope provides an estimate of the rate of change over time. In this study, Sen's Slope is applied to determine the magnitude of trends in both temperature and rainfall data, complementing the Mann-Kendall test by providing not only the direction but also the strength of observed changes. The equation below is used to estimate each individual slope (Q_i):

$$Q_i=\frac{y_{j-}y_i}{j-i} \quad (3)$$

where: $i = 1$ to $(n - 1)$ and $j = 2$ to n

y_j and y_i are data value at time j and i, and $j > i$.

If the time series, there are n values of y_j, estimate of the slope will be:

$$N=\frac{n(n-2)}{2} \quad (4)$$

The Sen's slope is:

$$Q_{ij}=\frac{y_{j-}y_i}{j-i} \quad \text{(if } n \text{ is odd)}$$
$$=\frac{1}{2}\left(Q\frac{N}{2}+Q\left[\frac{N+2}{2}\right]\right) \quad \text{(if } n \text{ is even)} \quad (5)$$

The positive value of Q_i indicates an increasing trend, and the negative value tell us that there is a negative trend.

3. RESULTS AND DISCUSSION

In figure 6 the measured precipitation values from the eight meteorological stations, including three located within the Bârzava basin and five in the adjacent regions are presented. The precipitation for the month of November, of each year, is presented in figure 7. Figure 8 presents the minimum average temperatures recorded over 40 years at the eight analyzed stations. In Table 2 we present the summary statistics of the data analyzed for trends in Bârzava catchment; the results of the Mann-Kendall test applied to monthly precipitation data are available in Table 3. In total, there were 62 observations for each month, and there were no missing datasets.

Table 2. Summary statistics for the analysed mean monthly temperature data

Months	Minimum	Maximum	Mean	Std. deviation
January	-11.75	1.50	-4.23	2.4
February	-11.25	2.75	-3.47	2.9
March	-6.00	5.00	0.09	2.6
April	-0.75	9.75	4.63	1.9
May	5.25	14.25	9.8	1.9
June	10.25	17.00	13.36	1.7
July	11.50	19.00	15.40	1.6
August	10.75	19.25	15.50	1.9
September	6.75	15.75	11.50	2.0
October	3.00	11.00	7.12	1.6
November	-4.50	7.00	1.90	2.3
December	-8.50	2.25	-2.92	2.1

Table 3. Kendal test values for precipitation.

Series\Test	Kendall's tau	p-value	Sen's slope
January	0.258	0.004	0.047
February	0.266	0.003	0.057
March	0.223	0.012	0.048
April	0.194	0.032	0.029
May	0.185	0.038	0.027
June	0.378	<0.0001	0.052
July	0.457	<0.0001	0.054
August	0.433	<0.0001	0.069
September	0.158	0.080	0.023
October	0.069	0.446	0.006
November	0.072	0.424	0.008
December	0.187	0.037	0.032

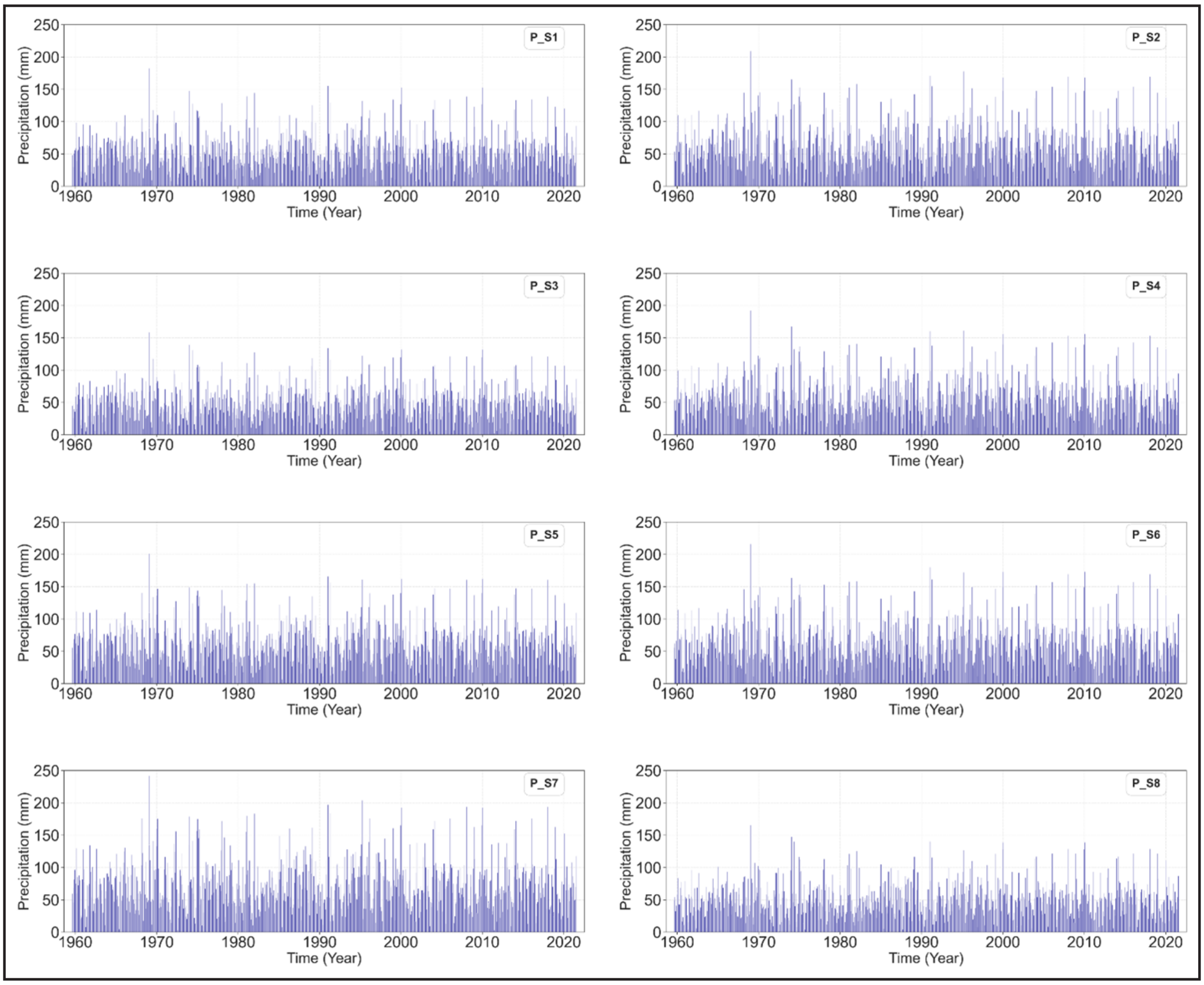

Fig. 6. Montly average anual precipitation.

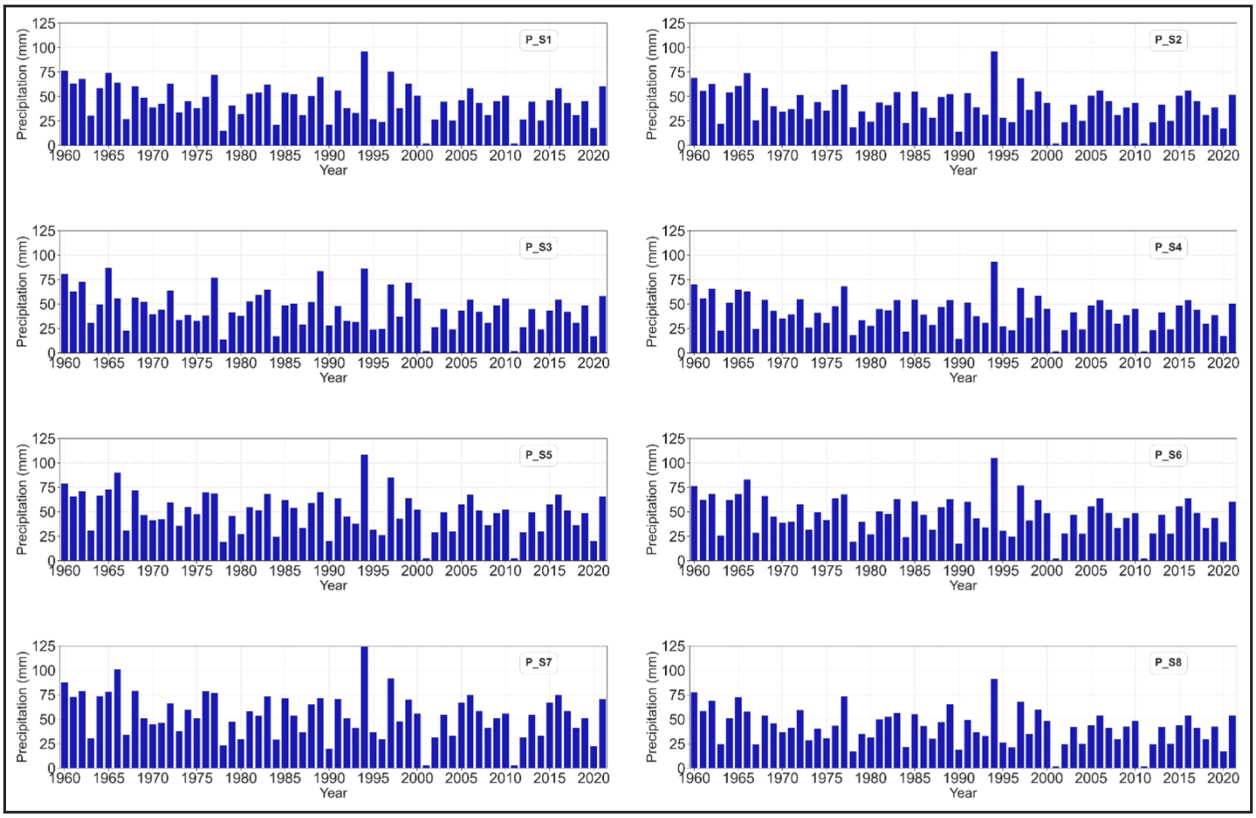

Fig. 7. November average precipitation at all 8 stations, for the period 1960-2021.

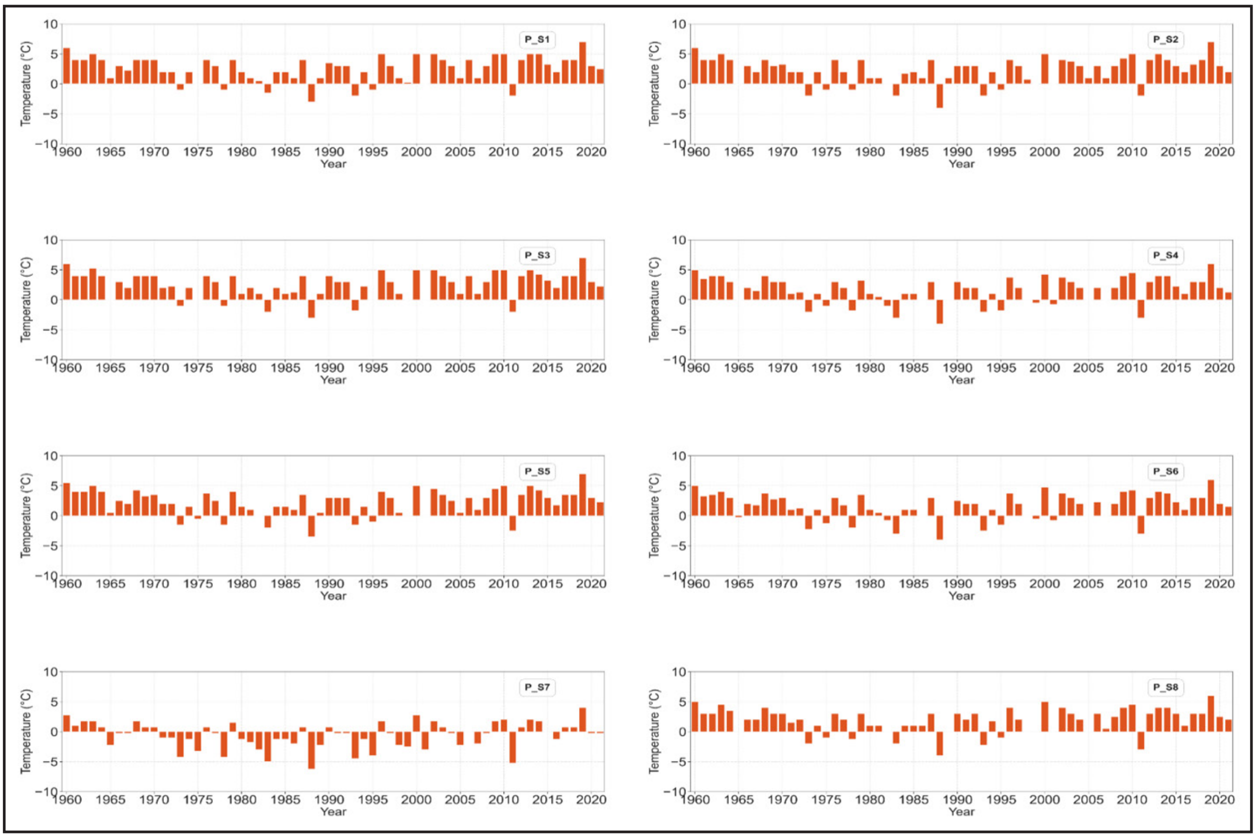

Fig. 8. Minimum montly average temperature in the eigth analysed stations.

Figure 9 shows the number of months with significant changes in climatic conditions for each station in the basin.

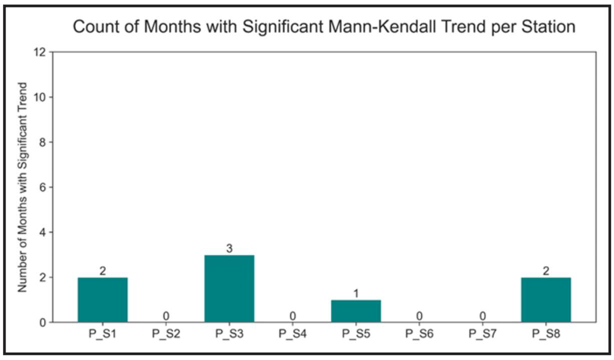

Fig. 9. Significant trends per station.

4. CONCLUSIONS

The analysis of precipitation and temperature across the Bârzava catchment over 1960–2021 reveals signals of hydro-climatic change, evident at the monthly scale, as data was available. Using the Mann-Kendall test with Sen's slope estimation, a majority of the examined series exhibit statistically significant upward monotonic trends, with the strongest increases occurring in June to August (τ up to about 0.46 and positive slopes on the order of 0.05-0.07 units per year), and additional significant increases in January till may and December. By contrast, September to November months show no detectable trend at the 5% significance level, indicating that not all the months or aggregates are changing uniformly. The prevalence of significant monthly trends suggests that changes are more pronounced in the intra-annual distribution than in the aggregated annual totals, consistent with a shift in timing and intensity rather than a uniform annual increase.

Spatially, precipitation remains highest in the Semenic Mountains and lowest in the plains, and early summer continues to concentrate the largest monthly totals, with June most frequently peaking at Oraviţa and July typically following. These patterns imply increasing hydrologic variability through altered rainfall intensity and evapotranspiration demand, raising the potential for both short-duration flood events in the warm season and for stressed low-flow periods other time and place in the year. The absence of significant seasonal-aggregate changes by station further shows that the signal emerges clearly at the monthly scale. While the IDW interpolation is appropriate for extending coverage given uneven station spacing, uncertainties may be higher in the lowlands where gauges are sparse and topographic controls are weaker than in the mountain sector. Overall, the evidence indicates that climate change is manifested in the region's precipitation regime, through shifting monthly behavior and intensification patterns that have practical implications for reservoir operation, flood protection, and water-supply reliability. Our findings imply that water management in the Bârzava basin should anticipate intraannual variability, which require tightening reservoir operations, strengthening flood protection, and safeguarding supplies during potential lowflow periods – while recognizing that uncertainties remain due to uneven gauge coverage (especially in lowlands).

REFERENCES

Bădăluţă-Minda, C., Herbei, M.V. (2022). Modelling the surface runoff in the Barzava basin based on geographic information systems and HEC GeoHMS, *Environmental Engineering and Management Journal*, **21**(*5*): 869-877.

Bengtsson, L., Rana, A. (2013). Long-term change of daily and multi-daily precipitation in southern Sweden. *Hydrological Processes*, **28**(*6*): 2897-2911.

Calvin, K., Dasgupta, D., Krinner, G., Mukherji, A., Thorne, P.W., Trisos, C., Romero, J., Aldunce, P., Barrett, K., Blanco, G. (2023). IPCC report: Summary for Policymakers. *In*: Core Writing Team, Lee, H., Romero, J. (Eds.): *Climate Change 2023: Synthesis Report.* Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change IPCC, Geneva, Switzerland: 1-34.

Croitoru, A.E, Holobaca I.H., Lazar, C., Moldovan F., Imbroane, A. (2012). Air temperature trend and the impact on winter wheat phenology in Romania. *Climate Change* **111**(*2*): 393-410.

Fortesa, J., Latron, J., García-Comendador, J., Tomàs-Burguera, M., Company, J., Calsamiglia, A., Estrany, J. (2020) Multiple Temporal Scales Assessment in the Hydrological Response of Small Mediterranean-Climate Catchments. *Water*, **12**: Article No. 299.

Hassaballah, K., Jonoski, A., Popescu, I., Solomatine, D.P. (2012) Model-based optimisation of downstream impact during filling of a new reservoir: case study of Mandaya/Roseires reservoirs on the Blue Nile River. *Water Resources Management*, **26**(*2*): 273-293.

Herbei, M.V., Bădăluţă-Minda, C., Popescu, C.A., Horablaga, A., Dragomir, L.O., Popescu, G., Kader, S., Sestras, P. (2024). Rainfall-runoff modeling based on HEC-HMS model: a case study in an area with increased groundwater discharge potential. *Frontiers in Water*, **6**: Article No. 1474990.

Jonoski, A., Ali, M.H., Bertini, C., Popescu, I., Van Andel, S.J., Lansu, A. (2025). Model-based design of drought-related climate adaptation strategies using nature-based solutions: case study of the Aa of Weerijs catchment in the Netherlands. *Nature-Based Solutions*, **8**: Article No. 100264.

Klein Tank, A.M.G., Können, G.P. (2003). Trends in indices of daily temperature and precipitation extremes in Europe 1946-99. *Journal of Climate*, **16**(*22*): 3665-3680.

Lhotka, O., Kyselý, J. (2022). Precipitation–temperature relationships over Europe in CORDEX regional climate models. *International Jornal of Climatolology*, **42**(*9*): 4868-4880.

Liebscher, E. (2021). Kendall regression coefficient. *Computational Statistics & Data Analysis*, **157**(*5*): Article No.107140.

Martel, J.L., Brissette, F.P., Lucas-Picher, P., Troin, M. Arsenault, R. (2021). Climate Change and Rainfall Intensity–Duration–Frequency Curves: Overview of Science and Guidelines for Adaptation. *Journal of Hydrologic Engineering*, **26**(*10*): Article No. 03121001.

Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I. (2021). Intergovernmental Panel on Climate Change (IPCC). *Climate Change, The Physical Science Basis*; Eds.; Cambridge University Press: Cambridge, 260 p.

Popescu, I., Teau, C., Moisescu-Ciocan, C., Florescu, C., Adam, R., Constantin, A.T. (2024). Evaluating the Sustainability of Longtime Operating Infrastructure for Romanian Flood Risk Protection. *Sustainability*, **16**(*23*): Article No. 10573.

Rosmann, T., Domínguez, E., Chavarro, J. (2016). Comparing trends in hydrometeorological average and extreme data sets around the world at different time scales. *Journal of Hydrology: Regional Studies*, **5**: 200-212.

Samadi, V., Fowler, H.J., Lamond, J., Wagener, T., Brunner, M., Gourley, J., Moradkhani, H., Popescu, I., Wasko, C., Wright, D., Wu, H., Zhang, K., Arias, P.A., Duan, Q., Nazemi, A., Van Oevelen, P.J., Prein, A.F., Roundy, J.K., Saberian, M., Umutoni, M. (2025). The Needs, Challenges, and Priorities for Advancing Global Flood Research. *WIREs Water*, **12**(*3*)*:* Art. no. 70026.

Schlef, K.E., Kunkel, K., Brown, C., Demissie,Y., Lettenmaier, D.P., Wagner, A., Wigmosta, M.S., Karl, T.R., Easterling, D.R., Wang, K.J., François, B., Yan, E. (2023). Incorporating non-stationarity from climate change into rainfall frequency and intensity-duration-frequency (IDF) curves. *Journal of Hydrology*, **616**: Article No. 128757.

Sen Roy S., Balling Jr., R.C. (2004). Trends in extreme daily precipitation indices in India. *International Journal of Climatology*, **24**: 457-466.

Spioni, J., Naumann, G., Vogt, J.V. (2017). Pan-European seasonal trends and recent changes of drought frequency and severity. *Global and Planetary Change*, **148**(*1*): 113-130.

Sun, Q.X., Zhang, F., Zwiers, S., Westra, L.V., Alexander, A. (2021). Global, continental, and regional analysis of changes in extreme precipitation. *Journal of Climatology*, **34**(*1*): 243-258.

Westra, S., Fowler, H.J., Evans, J.P., Alexander, L.V., Berg, P., Johnson, F., Kendon, E.J., Lenderik, G., Roberts, N.M. (2014). Future changes to the intensity and frequency of short-duration extreme rainfall. *Review of Geophysics*, **52**(*3*): 522-555.

https://wmo.int/sites/default/files/2025-03/WMO-1368-2024_en.pdf WMO Report, State of the Global Climate 2024, World Meteorological Organization, WMO-No. 1368.

https://oar.archi/reglementari-tehnice-2/constructii-2/reglementari-tehnice-privind-proiectarea-si-executarea-constructiilor-hidrotehnice-amenajarilor-si-regularizarilor-de-rauri/ Ordinul Arhitecților din România, 8.03.2021.