

Statistical Analysis of Long-Term Climate Data – Case Study on the Western Part of Romania between 1961 and 2020

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Abstract. Climate change is a reality, manifesting on a global scale, and with variable effects on the environment, human health, performance and socio-economic balances. This study analyzed climate data (temperature, precipitation) over a period of 60 years, between 1961 and 2020. The climate data were recorded in the Western area of Romania, at the Arad Meteorological Station and the Sannicolau Mare Meteorological Station. The multiannual calculated mean value over the study period for temperature (T , °C) was $\bar{T} = 10.92 \pm 0.11$ °C, and the multiannual average value calculated for precipitation (P , mm) was $\bar{P} = 564.54 \pm 14.17$ mm. In the case of temperature, the annual mean values, compared to the multiannual mean value, showed differences between $\Delta T = -1.44$ °C in the case of 1980 year, and $\Delta T = 1.76$ °C in the case of 2019 year. In the case of precipitation, the annual values, compared to the multiannual mean value, showed differences between $\Delta P = -289.04$ mm in the case of 2000 year, and $\Delta P = 234.56$ mm in the case of 2010 year. In the first half of the interval (1961 – 1990) only three years (1961, 1966 and 1990) presented the annual mean temperature above the multiannual mean, within statistical safety conditions ($p < 0.001$, ***). In the second half of the interval (1991 – 2020) temperature values above the multiannual mean were recorded in the case of 16 years, in statistical safety conditions. In the decade 1991 – 2000 three years presented temperature values above the multiannual mean (1992, 1994, and 2000), in the decade 2001 – 2010 four years (2002, 2007, 2008 and 2009) presented temperature values above the multiannual mean, and in the decade 2011 – 2020 nine consecutive years (2012 – 2020) presented temperature values above the multiannual mean. Multivariate analysis (PCA) explained the positioning, mode and action intensity of the monthly periods in the study interval according to the principal components, based on the values of climatic factors (T , °C; P , mm). Cluster analysis grouped the years in the study interval based on similarity in relation to the values of climatic parameters. Sinusoidal models described the variation of temperature ($p = 0.00026$) and precipitation ($p = 0.5955$) over the entire study interval. Ranking analysis ranked the years in the study interval in relation to temperature values and quartile threshold.

Keywords: climate data, clusters, dry years, PCA, rainfall deficit, trend models

INTRODUCTION

Climate change is occurring on a global scale, and its effect has been conceptually analyzed on agriculture, on global food patterns, as a causal relationship (Abbass et al., 2022; Hultgren et al., 2025). Associated with climate change, other effects on biodiversity, ecosystem variations, the presence and spread of pathogens and diseases, the tourism industry, ecological and socio-economic sustainability were also analyzed (Abbass et al., 2022).

Climate change, especially global warming, has generated changes in the planet's climate pattern, with an impact on natural and anthropogenic ecosystems, human health, performance and socio-economic balances (Zao et al., 2022). Climate change was analyzed as an impact on economic activities and supply chains, in order to understand the phenomenon and formulate solutions for the transition to a sustainable future (Papadopoulos and Balta, 2022). The major influence of climate change on human-made areas has been recorded, especially in urban ecosystems, with considerable effects on human comfort and health (Herbei and Sala, 2020; Shah and Sharifi, 2025).

Climate changes, in terms of precipitation and temperatures, over long time intervals, have been analyzed in relation to the negative economic impact, in representative regions throughout the world, and differentiated effects have been recorded in relation to the study locations and especially in relation to latitudinal levels (Kotz et al., 2024; Bearpark et al., 2025). In order to understand the variability of the thermal regime of flowing waters in relation to climate change and ecosystem health, the variation in water temperature was studied by analyzing long-term continuous data, between 1980 and 2018 (Shrestha and Pesklevits, 2023).

The analysis and evaluation of the dynamics and spatial and temporal variability of meteorological parameters is especially important for agricultural areas where agriculture is dominantly rain-fed (Haldar et al., 2023). Climate change has generated changes in the physicochemical and biological properties of the soil, with strongly negative effects on the physiological functions of crops (Bibi and Rahman, 2023). The effect of

technological inputs has diminished, with negative effects on farm yields and sustainability (Bibi and Rahman, 2023). Climate change affects farmers differently and with varying amplitude, in relation to the manifestation of climatic factors, such as high temperatures associated with drought, the time of year, the duration and intensity of heat waves and drought, precipitation and extreme climatic phenomena - hail, floods, etc. (Waqas et al., 2025).

To mitigate the negative effects of agriculture associated with climate change, the study of climate models and the use of mitigation and compensation strategies for climate effects is recommended (Bibi and Rahman, 2023). Farmers' adaptability to climate change is important for farm sustainability (Waqas et al., 2025). Global food systems are affected by climate change, with varying effects depending on the way they adapt (Hultgren et al., 2025). Some scenarios have indicated some notable consequences as a result of adapting agricultural production systems, but in reality agricultural producers adapt differently in the real world, so the consequences can have very variable effects (Hultgren et al., 2025).

Mathematical models and tests showed the upward trend in temperature (95% confidence) and precipitation by analyzing climate data over a long period of time, between 1970 - 2019 (Haldar et al., 2023). The authors estimated a faster increase in temperature and precipitation for the coming years (until 2029) for the studied area, and considered the models and results useful for management decisions (Haldar et al., 2023). New analysis methods, with updated algorithms, were considered necessary for analyzing large sets of climate data of the "Big Data" type for studying climate change, evaluating seasonal variations, and establishing potential risks for people, economic activities and the environment (Ikegwu et al., 2024).

In order to increase the accuracy of climate forecasting, "subseasonal temperature" estimation models were tested comparatively, and in relation to different study methods, variables (oceanic, terrestrial), input characteristics, grid points (Xue et al., 2025). Studies based on remote sensing, correlated with climate data, have generated values of specific indices and models of variation of climatic conditions for urban ecosystems, for the purpose of management support decisions in ensuring urban resilience (Herbei and Sala, 2020; Medina et al., 2024; Shah and Sharifi, 2025; Zhu and Feng, 2025).

Studies on climate data have generated various models for machine learning, prediction, and finding "breakpoints" in temperature and precipitation prediction models (Pavan Kumar et al., 2025). Drought indices have been evaluated in regional-scale climate simulation studies, starting from global climate models (Cheung et al., 2025). Temperature is an important indicator for assessing changes in the Earth's energy balance, and is a determining factor for ecological and environmental processes, so studies of thermal variation have shown great interest (Lindsey and Dahlman, 2025). Trends in variation of climatic indices (e.g. precipitation) were analyzed in the specifics of the Mediterranean area, where the rainfall regime and precipitation patterns are of high importance from a hydrological perspective, of water resources, with an impact on agriculture and some socio-economic aspects (Yavaşlı, 2025).

Climate change is a major concern on a global scale, and for the assessment of the impact, socio-economic and environmental risks, and especially for the development of strategies to mitigate the associated risks, special attention is paid to understanding the patterns, models and trends of manifestation and variation (Yilmaz and Birdal, 2025). Mathematical analysis used in conjunction with remote sensing and GIS data ensured high reliability in the study of climate data and described with high accuracy the trends in climate variation for the study area (Yilmaz and Birdal, 2025).

Through climate studies and plant samples, a positive correlation was recorded in the growth of some test plant species (e.g. cedar trees) with precipitation and a negative correlation with temperature (Misra et al., 2025). Response functions and linear regression models showed the favorable climatic conditions for the growth of tree species in the study area (Misra et al., 2025). The recorded results were useful for understanding and explaining the hydroclimatic variability in the study area.

The present study analyzed long-term climate data, recorded over a period of 60 years (1961 - 2020), and used different methods and statistical analysis tools to characterize the variation of climate parameters, temperature and precipitation, over the study interval.

MATERIAL AND METHODS

In relation to the purpose of the study, climate data recorded between 1961 and 2020 in the Western area of Romania, at the Arad Meteorological Station and the Sannicolau Mare Meteorological Station, were used.

The climatic data used in the study was represented by temperature (T, °C) and precipitation (P, mm). In the case of temperature, the monthly mean value was considered in the study, and in the case of precipitation, the amount of monthly precipitation was considered, for each year, during the study period. Based on the primary data, annual and multiannual means were calculated.

The study for the article was conducted based on the flow chart (Figure 1), which includes the work stages in the analysis of climate, temperature and precipitation data, recorded by year, during the study period (1961 - 2020).

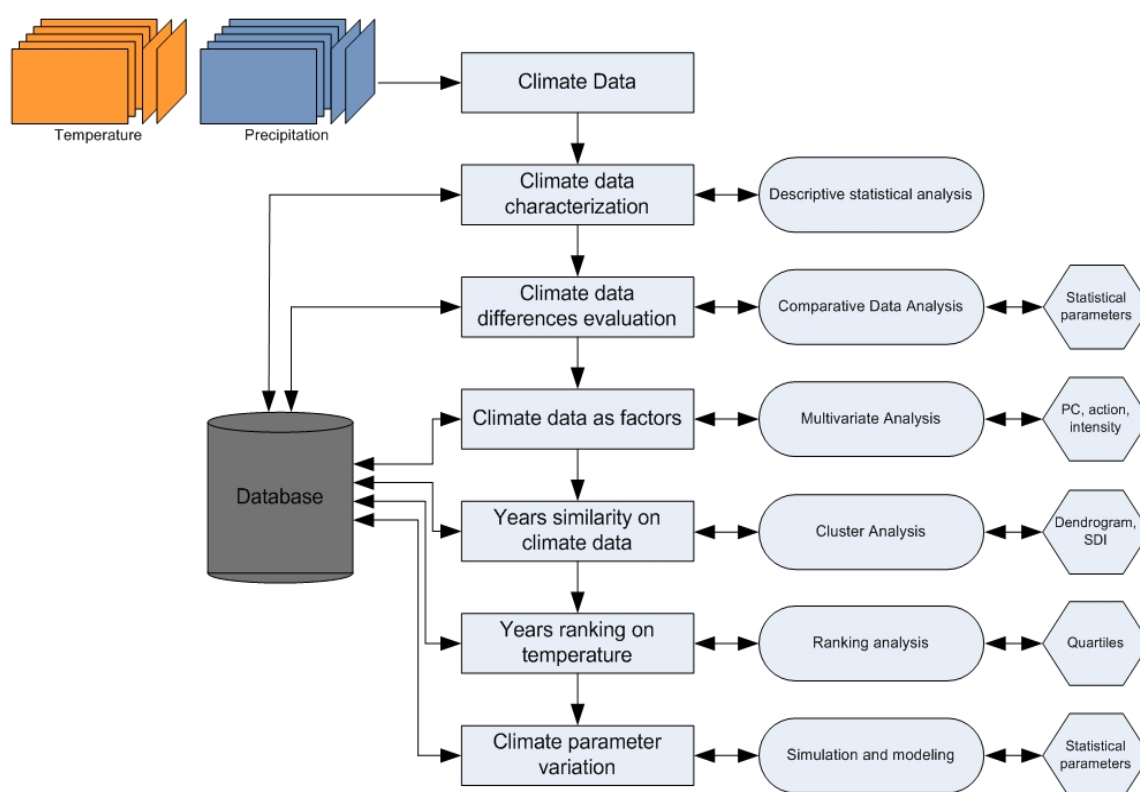


Figure 1. Flowchart in studying climate data

Descriptive statistical analysis was applied to the climatic data series (temperature, precipitation) to characterize the recorded values by specific statistical parameters. The statistical reliability and the presence of variance in the data series was evaluated (ANOVA Test).

The comparative analysis was performed for the climatic data series, whereby the values of each year were analyzed in relation to the multiannual average, for temperature and for precipitation. The level of differences of the climatic values of each year (temperature, precipitation), in relation to the multiannual average was analyzed based on the thresholds $p < 0.05\%$, $p < 0.01\%$ and $p < 0.001\%$ respectively. The level of significance of the values of climatic parameters (temperature, precipitation) between the study years was evaluated using Dunn's Post Hoc Test.

Multivariate analysis was applied to find out the positioning of each month (as influencing factors) in relation to the principal components, based on climatic values (temperatures, precipitation). The grouping of years based on similarity in relation to the values of climatic parameters (temperatures, precipitation) was evaluated through Cluster Analysis. The grouping of years into quartiles, and the ranking of years within each quartile was evaluated. The modeling of the variation of climatic parameters (temperature, precipitation) was studied both over the entire period and for shorter segments, in recent decades.

In relation to the statistical analyses and tests applied, appropriate software was used, PAST v 4.17 (Hammer et al., 2001), JASP v 0.16.2 (JASP, 2022).

RESULTS AND DISCUSSIONS

The climatic data for the 1961 - 2020 period were analyzed for general statistical characterization. The values of the statistical parameters for the thermal regime (Table 1) and for the pluviometric regime (Table 2) resulted. The average values for the study years for the thermal regime are presented in Figure 2, and the values for the pluviometric regime are presented in Figure 3.

Table 1. Values of statistical parameters for the thermal regime, 1961 – 2020 period

Parameters	Monthly statistical values												Mean T
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Valid	60	60	60	60	60	60	60	60	60	60	60	60	60
Missing	0	0	0	0	0	0	0	0	0	0	0	0	0
Median	-0.85	1.55	5.75	11.35	16.70	20.00	21.75	21.10	16.60	11.10	5.75	1.00	10.83
Mean	-1.09	1.09	5.72	11.36	16.57	20.02	21.79	21.38	16.68	11.11	5.65	0.77	10.92
Std. Error of Mean	0.35	0.41	0.27	0.21	0.19	0.18	0.18	0.22	0.21	0.20	0.29	0.27	0.11
Std. Deviation	2.70	3.16	2.11	1.62	1.51	1.40	1.41	1.71	1.66	1.56	2.24	2.09	0.81
Coefficient of variation	-2.47	2.91	0.37	0.14	0.09	0.07	0.07	0.08	0.10	0.14	0.40	2.71	0.08
Skewness	-0.81	-0.55	-0.46	-0.01	-0.10	0.04	0.20	0.34	0.10	0.16	-0.33	-0.48	0.35
Std. Error of Skewness	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Kurtosis	1.11	-0.24	-0.35	0.33	-0.15	-0.15	-0.38	-0.11	-0.46	0.32	0.32	0.10	-0.64
Std. Error of Kurtosis	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
Shapiro-Wilk	0.95	0.96	0.96	0.99	0.99	0.99	0.99	0.98	0.99	0.99	0.99	0.97	0.97
P-value of Shapiro-Wilk	0.02	0.06	0.08	0.99	0.94	0.99	0.72	0.59	0.96	0.67	0.74	0.14	0.12
Minimum	-9.50	-6.20	0.00	7.20	12.90	16.70	19.00	17.40	13.10	8.00	-0.90	-4.30	9.48
Maximum	4.20	6.60	8.80	15.60	20.00	23.20	25.10	25.90	20.40	15.80	10.50	5.00	12.68
25th percentile	-2.20	-0.83	4.38	10.38	15.80	19.18	20.90	20.15	15.58	10.10	3.98	-0.40	10.32
50th percentile	-0.85	1.55	5.75	11.35	16.70	20.00	21.75	21.10	16.60	11.10	5.75	1.00	10.83
75th percentile	0.60	3.23	7.60	12.33	17.60	20.93	22.65	22.53	17.83	12.10	7.15	2.30	11.51

Notes: I to XII calendar months; Mean T – calculated mean temperature (T, °C)

Table 2. Values of statistical parameters for the rainfall regime, 1961 – 2020 period

Parameters	Monthly statistical values												Amount P
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Valid	60	60	60	60	60	60	60	60	60	60	60	60	60
Missing	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean	34.59	32.30	34.58	44.49	57.23	77.11	59.27	52.10	44.22	39.85	43.04	45.78	564.54
Std. Error of Mean	2.75	2.89	3.20	3.04	3.84	5.28	3.97	4.42	3.45	4.11	3.48	3.61	14.18
Std. Deviation	21.29	22.39	24.78	23.54	29.73	40.89	30.78	34.23	26.72	31.83	26.96	27.94	109.83
Coefficient of variation	0.62	0.69	0.72	0.53	0.52	0.53	0.52	0.66	0.60	0.80	0.63	0.61	0.20
Skewness	0.35	0.85	1.54	0.92	0.78	1.01	1.20	0.70	0.71	1.08	0.77	0.88	-0.06
Std. Error of Skewness	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Kurtosis	-0.75	0.01	4.28	1.54	0.14	1.03	1.31	0.25	1.17	1.08	0.06	1.11	-0.34
Std. Error of Kurtosis	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
Shapiro-Wilk	0.96	0.92	0.89	0.95	0.95	0.93	0.90	0.95	0.96	0.91	0.94	0.96	0.99
P-value of Shapiro-Wilk	0.04	< .001	< .001	0.02	0.01	0.00	< .001	0.01	0.04	< .001	0.01	0.03	0.83
Minimum	2.40	1.60	1.10	0.00	7.70	18.40	14.60	2.40	0.80	0.80	0.10	0.10	275.50
Maximum	84.70	96.50	139.80	127.60	140.00	213.00	149.70	157.80	137.80	141.00	112.60	137.70	799.10
25th percentile	17.20	15.33	15.60	26.98	35.93	50.33	36.08	21.90	23.43	15.05	21.23	24.68	482.78
50th percentile	33.50	25.40	30.40	40.10	52.05	66.90	57.20	46.20	43.35	36.00	37.00	42.00	570.50
75th percentile	48.73	47.38	46.23	56.70	74.70	96.85	70.35	79.10	62.53	57.10	56.88	61.45	637.63

Notes: I to XII calendar months; Amount P – calculated amount of precipitation (P, mm)

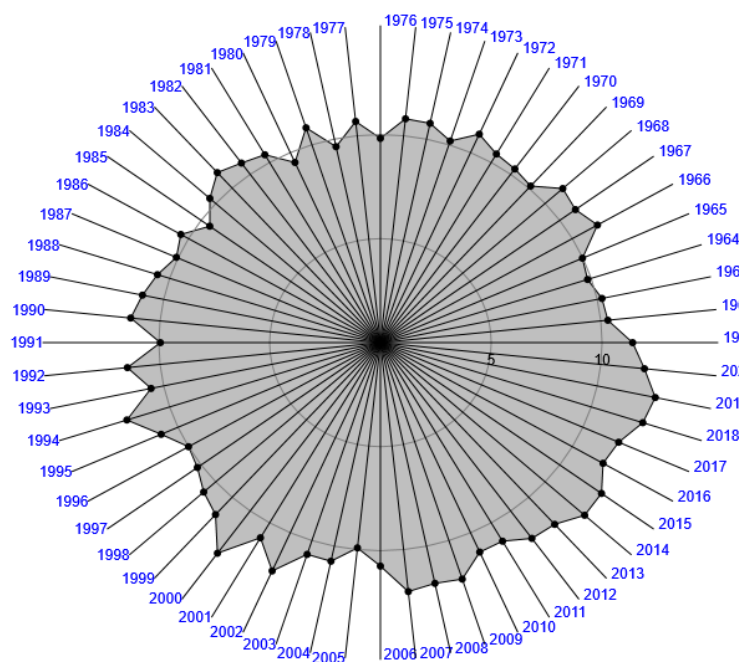


Figure 2. Graphical distribution of annual mean temperature values during the study period

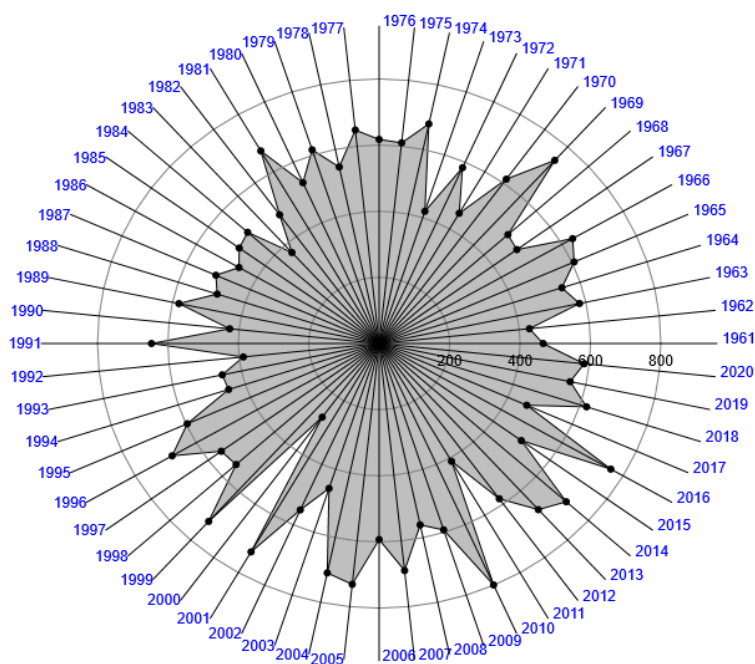


Figure 3. Graphical distribution of annual amount precipitation values over the study period

The statistical reliability of the data and the presence of variance in the data set were confirmed, according to ANOVA Test, Alpha = 0.05 ($F > F_{crit}$, $p = 0$). The comparative analysis was made between the monthly average values of temperature and the monthly values of precipitation. In the case of the thermal regime, values were obtained according to which in most cases there were statistically significant differences between the thermal values per month, in the years of study (Table 3). In the case of precipitation, differences were recorded within statistical certainty, but also many situations in which the differences between certain months did not present statistical certainty (Table 4).

Table 3. Dunn's Post hoc test results for monthly mean temperature, during the study period

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
I		0.1671	1.33E-05	6.79E-15	7.71E-28	1.63E-43	8.44E-54	5.87E-51	2.77E-28	2.19E-14	1.66E-05	0.2969
II	0.1671		0.0030	1.49E-10	1.24E-21	1.38E-35	6.57E-45	2.54E-42	5.04E-22	3.91E-10	0.0034	0.7351
III	1.33E-05	0.00295		0.0006	4.64E-11	2.59E-21	1.43E-28	1.56E-26	2.48E-11	0.0010	0.9618	0.0009
IV	6.79E-15	1.49E-10	0.000595		0.0016	1.50E-09	1.94E-14	4.96E-13	0.0012	0.8814	0.0005	1.53E-11
V	7.71E-28	1.24E-21	4.64E-11	0.001644		0.0038	6.60E-06	4.54E-05	0.9264	0.0010	3.36E-11	4.45E-23
VI	1.63E-43	1.38E-35	2.59E-21	1.50E-09	0.003781		0.1073	0.2370	0.0051	5.90E-10	1.64E-21	1.88E-37
VII	8.44E-54	6.57E-45	1.43E-28	1.94E-14	6.60E-06	0.1073		0.6687	1.02E-05	6.02E-15	8.36E-29	5.20E-47
VIII	5.87E-51	2.54E-42	1.56E-26	4.96E-13	4.54E-05	0.2370	0.6687		6.72E-05	1.64E-13	9.31E-27	2.32E-44
IX	2.77E-28	5.04E-22	2.48E-11	0.0012	0.9264	0.0051	1.02E-05	6.72E-05		0.0007	1.79E-11	1.76E-23
X	2.19E-14	3.91E-10	0.0010	0.8814	0.0010	5.90E-10	6.02E-15	1.64E-13	0.0007		0.0009	4.22E-11
XI	1.66E-05	0.0034	0.9618	0.0005	3.36E-11	1.64E-21	8.36E-29	9.31E-27	1.79E-11	0.0009		0.0011
XII	0.2969	0.7351	0.0009	1.53E-11	4.45E-23	1.88E-37	5.20E-47	2.32E-44	1.76E-23	4.22E-11	0.0011	

Table 4. Dunn's Post hoc test results for precipitation, monthly amount, over the study period

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
I		0.5232	0.7957	0.0415	3.61E-05	9.85E-11	8.33E-06	0.0040	0.0618	0.5598	0.1337	0.0379
II	0.5232		0.7044	0.0074	1.85E-06	1.18E-12	3.49E-07	0.0004	0.0122	0.2219	0.0325	0.0066
III	0.7957	0.7044		0.0216	1.13E-05	1.72E-11	2.41E-06	0.0017	0.0335	0.3998	0.0787	0.0196
IV	0.0415	0.0074	0.0216		0.0364	9.41E-06	0.0156	0.4004	0.8639	0.1454	0.5896	0.9706
V	3.61E-05	1.85E-06	1.13E-05	0.03642		0.0194	0.7448	0.2108	0.0236	0.0004	0.0085	0.0398
VI	9.85E-11	1.18E-12	1.72E-11	9.41E-06	0.0194		0.0442	0.000332	4.19E-06	3.95E-09	6.71E-07	1.12E-05
VII	8.33E-06	3.49E-07	2.41E-06	0.01562	0.7448	0.0442		0.1149	0.0096	0.0001	0.0031	0.0173
VIII	0.0040	0.0004	0.0017	0.4004	0.2108	0.0003	0.1149		0.3114	0.0216	0.1675	0.4214
IX	0.0618	0.0122	0.0335	0.8639	0.0236	4.19E-06	0.0096	0.3114		0.1990	0.7129	0.8350
X	0.5598	0.2219	0.3998	0.1454	0.0004	3.95E-09	0.0001	0.0216	0.1990		0.3594	0.1355
XI	0.1337	0.0325	0.0787	0.5896	0.0085	6.71E-07	0.0031	0.1675	0.7129	0.3594		0.5644
XII	0.0379	0.0066	0.0196	0.9706	0.0398	1.12E-05	0.0173	0.4214	0.8350	0.1355	0.5644	

The difference between the values of climatic parameters (temperature - T , °C; precipitation - P , mm) over the years and the calculated mean value of temperature ($\bar{T}$, °C), respectively of precipitation ($\bar{P}$, mm) over the study period was analyzed. The mean value calculated over the study period for temperature was $\bar{T} = 10.92^\circ\text{C}$, and the mean value calculated for precipitation was $\bar{P} = 564.54$ mm. In the case of temperature, the annual values compared to the average value showed differences ranging between $\Delta T = -1.44^\circ\text{C}$ in the case of 1980 and $\Delta T = 1.76^\circ\text{C}$ in the case of 2019 (Table 5, Figure 4 and Figure 5). In the case of precipitation, the annual values compared to the average value showed differences between $\Delta P = -289.04$ mm in the case of 2000 and $\Delta P = 234.56$ mm in the case of 2010 (Table 5, Figure 6, and Figure 7).

In the case of the thermal regime, an analysis was made for shorter periods of time, within the study interval. Thus, in the first half of the interval (1961 – 1990) only three years presented thermal values above the average calculated under conditions of statistical safety (***), namely the years 1961, 1966 and 1990 (Table 5). In the second half of the interval (1991 – 2020) thermal values above the calculated average were recorded, within statistical safety conditions, in the case of 16 years (Table 5). Within the period 1991 – 2020 (second half of the study interval), in the decade 1991 – 2000 three years presented thermal values above the calculated average value (1992, 1994, 2000). In the decade 2001 – 2010, thermal values above the calculated average were recorded in four years (2002, 2007, 2008 and 2009). In the decade 2011 – 2020, thermal values above the calculated average were recorded in nine consecutive years, 2012 – 2020, within statistical safety conditions (Table 5, Figure 4, and Figure 5).

Table 5. Calculated differences and statistical significance for climatic parameters during the study period

Year	Temperature (°C)				Precipitation (mm)			
	Difference:	95% conf. interval:	t :	p (same mean):	Difference:	95% conf. interval:	t :	p (same mean):
1961	0.46 ***	(0.24808 0.66859)	-4.362	5.25E-05	-98.74 ^{ooo}	(70.369 127.11)	6.964	3.12E-09
1962	-0.60 ^{ooo}	(0.39141 0.81192)	5.726	3.67E-07	-135.54 ^{ooo}	(107.17 163.91)	9.559	1.35E-13
1963	-0.70 ^{ooo}	(0.49141 0.91192)	6.678	9.48E-09	17.26 ***	(-11.115 45.631)	-1.217	2.28E-01
1964	-1.09 ^{ooo}	(0.88141 1.3019)	10.389	6.03E-15	-18.94 ^{ooo}	(-9.4314 47.315)	1.336	1.87E-01
1965	-0.94 ^{ooo}	(0.73141 1.1519)	8.962	1.32E-12	41.66 ***	(13.285 70.031)	-2.938	4.71E-03
1966	0.39 ***	(0.17808 0.59859)	-3.696	0.0005	70.06 ***	(41.685 98.431)	-4.941	6.75E-06
1967	-0.04 ^{ns}	(-0.16859 0.25192)	0.397	0.6931	-81.24 ^{ooo}	(52.869 109.61)	5.730	3.62E-07
1968	0.15 ^{ns}	(-0.061921 0.35859)	-1.412	0.1633	-72.54 ^{ooo}	(44.169 100.91)	5.116	3.57E-06
1969	-0.79 ^{ooo}	(0.58141 1.0019)	7.534	3.36E-10	180.66 ***	(152.29 209.03)	-12.741	1.38E-18
1970	-0.60 ^{ooo}	(0.39141 0.81192)	5.726	3.67E-07	49.76 ***	(21.385 78.131)	-3.509	8.67E-04
1971	-0.45 ^{ooo}	(0.24141 0.66192)	4.299	6.53E-05	-109.74 ^{ooo}	(81.369 138.11)	7.740	1.51E-10
1972	0.05 ^{ns}	(-0.16192 0.25859)	-0.460	0.6472	17.56 ^{ns}	(-10.815 45.931)	-1.238	0.2205
1973	-0.73 ^{ooo}	(0.52141 0.94192)	6.963	3.12E-09	-144.24 ^{ooo}	(115.87 172.61)	10.173	1.35E-14
1974	-0.14 ^{ns}	(-0.068588 0.35192)	1.348	0.1827	114.36 ***	(85.985 142.73)	-8.065	4.25E-11
1975	-0.10 ^{ns}	(-0.10859 0.31192)	0.968	0.3372	45.56 **	(17.185 73.931)	-3.213	0.0021
1976	-1.10 ^{ooo}	(0.89141 1.3119)	10.485	4.24E-15	52.56 ***	(24.185 80.931)	-3.707	4.66E-04
1977	-0.23 ^o	(0.021412 0.44192)	2.205	0.0314	84.56 ***	(56.185 112.93)	-5.963	1.49E-07
1978	-1.29 ^{ooo}	(1.0814 1.5019)	12.293	6.48E-18	-48.84 ^{ooo}	(20.469 77.215)	3.445	1.06E-03
1979	-0.06 ^{ns}	(-0.14859 0.27192)	0.587	0.5595	51.26 ***	(22.885 79.631)	-3.615	0.0006
1980	-1.44 ^{ooo}	(1.2314 1.6519)	13.720	5.18E-20	-32.14 ^{ooo}	(3.7686 60.515)	2.267	2.71E-02
1981	-0.49 ^{ooo}	(0.28141 0.70192)	4.679	1.73E-05	108.06 ***	(79.685 136.43)	-7.621	2.40E-10
1982	-0.25 ^o	(0.041412 0.46192)	2.395	0.0198	-83.34 ^{ooo}	(54.969 111.71)	5.878	2.06E-07
1983	0.08 ^{ns}	(-0.13192 0.28859)	-0.746	0.4589	-194.34 ^{ooo}	(165.97 222.71)	13.706	5.43E-20
1984	-0.56 ^{ooo}	(0.35141 0.77192)	5.345	1.53E-06	-62.04 ^{ooo}	(33.669 90.415)	4.376	5.01E-05
1985	-1.40 ^{ooo}	(1.1914 1.6119)	13.340	1.83E-19	-73.24 ^{ooo}	(44.869 101.61)	5.165	2.98E-06
1986	-0.52 ^{ooo}	(0.31141 0.73192)	4.965	6.19E-06	-104.84 ^{ooo}	(76.469 133.21)	7.394	5.82E-10
1987	-0.84 ^{ooo}	(0.63141 1.0519)	8.010	5.26E-11	-57.04 ^{ooo}	(28.669 85.415)	4.023	1.66E-04
1988	-0.34 ^{oo}	(0.13141 0.55192)	3.252	0.0019	-80.74 ^{ooo}	(52.369 109.11)	5.694	4.13E-07
1989	0.06 ^{ns}	(-0.15192 0.26859)	-0.555	0.5809	16.86 ^{ns}	(-11.515 45.231)	-1.189	0.2392
1990	0.41 ***	(0.19808 0.61859)	-3.886	0.0003	-137.64 ^{ooo}	(109.27 166.01)	9.707	7.74E-14
1991	-0.99 ^{ooo}	(0.78141 1.2019)	9.438	2.15E-13	82.16 ***	(53.785 110.53)	-5.794	2.83E-07
1992	0.56 ***	(0.34808 0.76859)	-5.314	1.72E-06	-176.64 ^{ooo}	(148.27 205.01)	12.458	3.66E-18
1993	-0.34 ^{oo}	(0.13141 0.55192)	3.252	0.0019	-108.84 ^{ooo}	(80.469 137.21)	7.676	1.93E-10
1994	1.11 ***	(0.89808 1.3186)	-10.548	3.35E-15	-114.94 ^{ooo}	(86.569 143.31)	8.106	3.62E-11
1995	-0.09 ^{ns}	(-0.11859 0.30192)	0.872	0.3865	32.26 *	(3.8853 60.631)	-2.275	0.0266
1996	-0.92 ^{ooo}	(0.71141 1.1319)	8.772	2.75E-12	114.46 ***	(86.085 142.83)	-8.072	4.13E-11
1997	-0.71 ^{ooo}	(0.50141 0.92192)	6.773	6.55E-09	-10.24 ^{ooo}	(-18.131 38.615)	0.722	4.73E-01
1998	0.19 ^{ns}	(-0.018588 0.40192)	1.824	0.0732	-17.64	(-10.731 46.015)	1.244	0.2184
1999	0.20 ^{ns}	(-0.011921 0.40859)	-1.888	0.0640	159.26 ***	(130.89 187.63)	-11.232	2.77E-16
2000	1.59 ***	(1.3781 1.7986)	-15.116	5.93E-22	-289.04 ^{ooo}	(260.67 317.41)	20.385	2.15E-28
2001	-0.09 ^{ns}	(-0.11859 0.30192)	0.872	0.3865	163.06 ***	(134.69 191.43)	-11.500	1.06E-16
2002	1.09 ***	(0.87808 1.2986)	-10.358	6.78E-15	-13.74 ^{ooo}	(-14.631 42.115)	0.969	3.36E-01
2003	-0.22 ^o	(0.011412 0.43192)	2.110	0.0391	-103.94 ^{ooo}	(75.569 132.31)	7.330	7.45E-10
2004	-0.18	(-0.028588 0.39192)	1.729	0.0891	144.66 ***	(116.29 173.03)	-10.202	1.21E-14
2005	-1.00 ^{ooo}	(0.79141 1.2119)	9.533	1.50E-13	167.66 ***	(139.29 196.03)	-11.824	3.35E-17
2006	-0.18 ^{ns}	(-0.028588 0.39192)	1.729	0.0891	28.16 ^{ns}	(-0.2147 56.531)	-1.986	0.051702
2007	1.11 ***	(0.89808 1.3186)	-10.548	3.35E-15	125.86 ***	(97.485 154.23)	-8.876	1.84E-12
2008	0.91 ***	(0.69808 1.1186)	-8.645	4.49E-12	-3.84 ^{ooo}	(-24.531 32.215)	0.271	7.87E-01
2009	1.03 ***	(0.81808 1.2386)	-9.787	5.73E-14	28.06 ***	(-0.3147 56.431)	-1.979	5.25E-02
2010	0.10 ^{ns}	(-0.11192 0.30859)	-0.936	0.3532	234.56 ***	(206.19 262.93)	-16.542	7.90E-24
2011	0.10 ^{ns}	(-0.11192 0.30859)	-0.936	0.3532	-153.54 ^{ooo}	(125.17 181.91)	10.828	1.20E-15
2012	0.71 ***	(0.49808 0.91859)	-6.741	7.41E-09	15.76 ***	(-12.615 44.131)	-1.111	2.71E-01
2013	0.83 ***	(0.61808 1.0386)	-7.883	8.62E-11	111.36 ***	(82.985 139.73)	-7.854	9.68E-11
2014	1.48 ***	(1.2681 1.6886)	-14.069	1.66E-20	150.46 ***	(122.09 178.83)	-10.611	2.66E-15
2015	1.41 ***	(1.1981 1.6186)	-13.403	1.48E-19	-65.44 ^{ooo}	(37.069 93.815)	4.615	2.17E-05
2016	0.68 ***	(0.46808 0.88859)	-6.456	2.24E-08	195.16 ***	(166.79 223.53)	-13.763	4.50E-20
2017	0.85 ***	(0.63808 1.0586)	-8.074	4.11E-11	-105.74 ^{ooo}	(77.369 134.11)	7.457	4.54E-10
2018	1.53 ***	(1.3181 1.7386)	-14.545	3.58E-21	54.86 ***	(26.485 83.231)	-3.869	2.76E-04
2019	1.76 ***	(1.5481 1.9686)	-16.734	4.50E-24	-10.04 ^{ooo}	(-18.331 38.415)	0.708	4.82E-01
2020	1.06 ***	(0.84808 1.2686)	-10.072	1.96E-14	20.96 ***	(-7.4147 49.331)	-1.478	1.45E-01

Note: p<0.05, * in case of positive differences, ^o in case of negative differences; p<0.01, ** in case of positive differences, ^{oo} in case of negative differences; p<0.001 *** in case of positive differences, ^{ooo} in case of negative differences; p>0.05, ns (not significance)

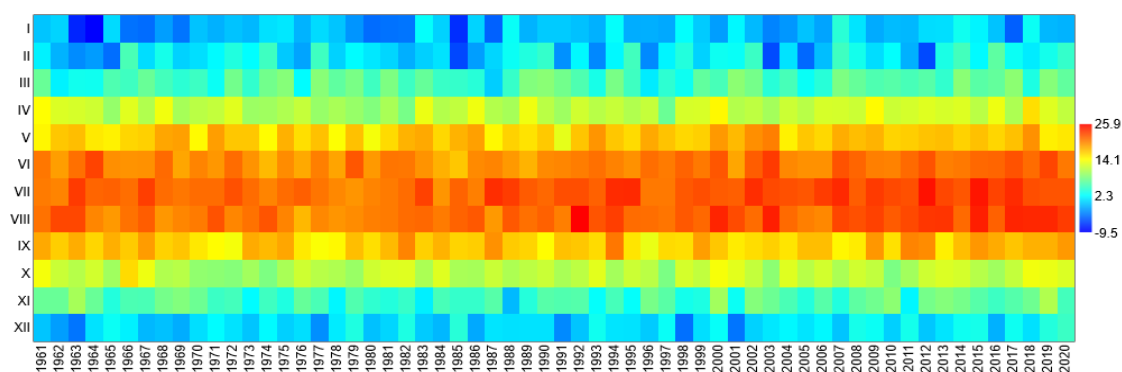


Figure 4. Matrix representing thermal values during the study period, 1961 – 2020

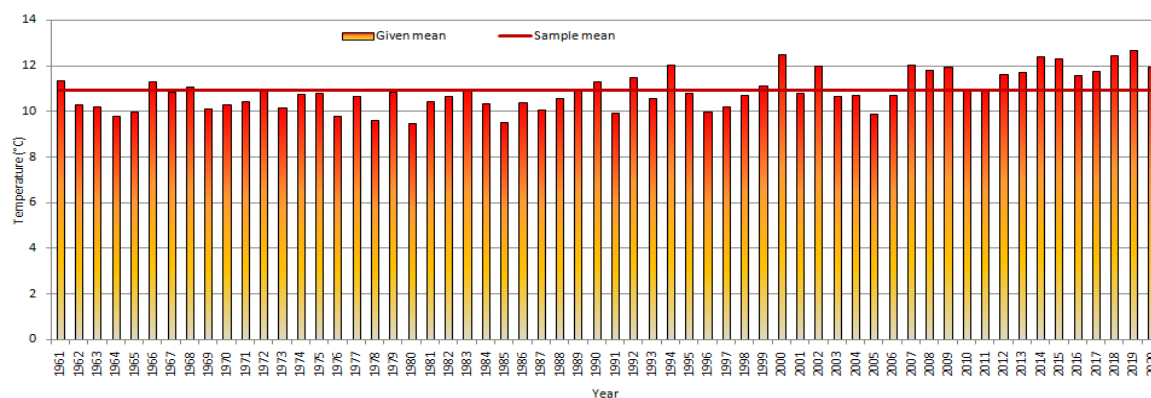


Figure 5. Graphic representation of thermal values in relation to the average value during the study period

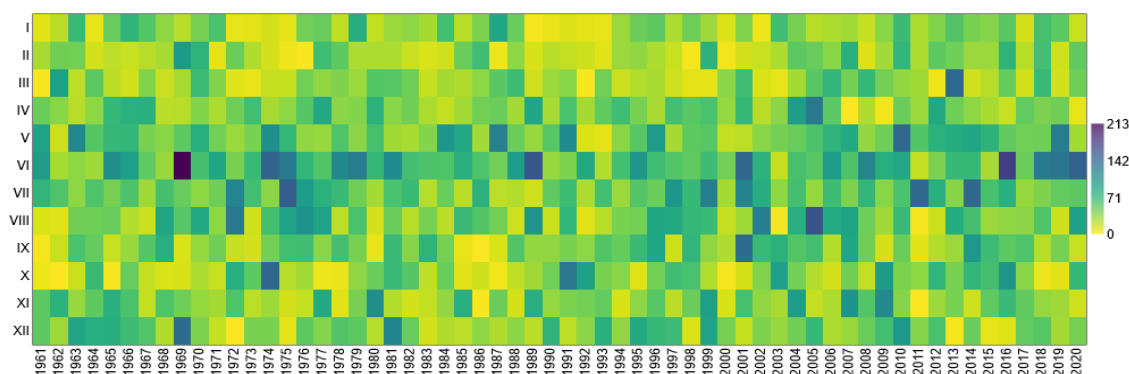


Figure 6. Precipitation representation matrix during the study period

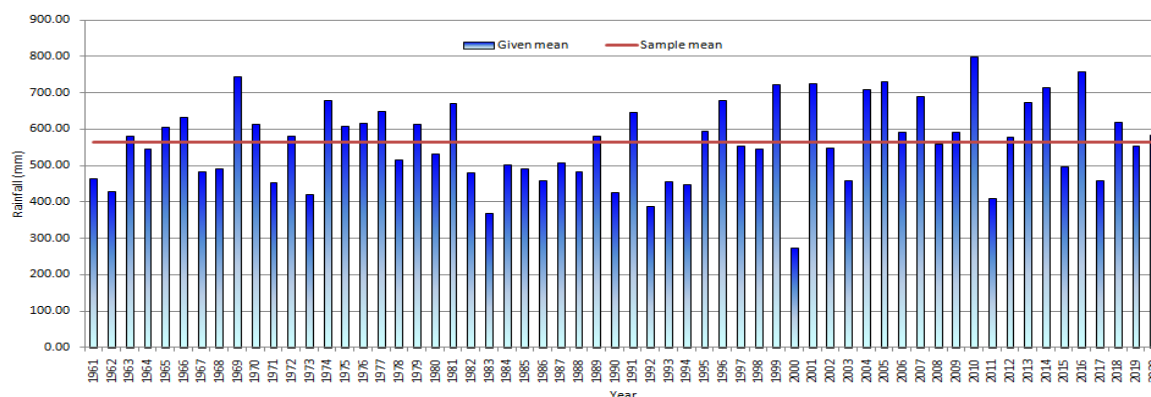


Figure 7. Graphical representation of precipitation values in relation to the average value during the study period

The average temperature over the last decade of the study period (2011 – 2020) was at $\bar{T}_{(2011 - 2020)} = 10.92\text{ }^{\circ}\text{C}$, with an increase of $\Delta T_{(2011 - 2020)} = 1.04\text{ }^{\circ}\text{C}$ compared to the average temperature over the entire study period. In the case of the rainfall regime, positive differences (rainfall surplus) compared to the multiannual average ($\bar{P} = 564.54\text{ mm}$) were recorded in statistically safe conditions in the case of 27 years, and negative differences (rainfall deficit) in the case of 29 years. Similarly to the analysis for the thermal regime, the time distribution of the years was analyzed in terms of the rainfall regime. Thus, in the first half of the study interval (1961 – 1990), there were 11 years with a rainfall surplus and 17 years with a rainfall deficit compared to the average calculated for the entire study period. In the second half of the study interval (1991 – 2020), there were 16 years with a rainfall surplus and 12 years with a rainfall deficit, compared to the average calculated for the entire study interval. The year 2000 was recorded with the highest rainfall deficit over the entire study period, $P(2000) = 275.00\text{ mm}$. From the analysis of the recorded results, it was observed that the years with rainfall deficit were flanked by years with precipitation values above the multiannual average (Table 5, Figure 7). Thus, for the last two decades, the year 2017 (with a rainfall deficit) was observed, which was flanked by the years 2015, 2017 (with a rainfall surplus); the year 2015 was flanked by the years 2014 and 2016; the year 2011 was flanked by the years 2010 and 2012; the years 2002, 2003 were flanked by the years 2001, 2004; the year 2000 was flanked by the years 1999, 2001. A similar pattern was observed for the first half of the study period, with certain particularities. A more prolonged period of rainfall deficit, with values recorded below the calculated average, was in the period 1982 - 1988, when in seven consecutive years there were rainfall values below the calculated average over the entire study period.

To explain the positioning of the climatic parameters (months, based on temperature and precipitation; Mean T; Amount P) as factors in relation to the principal components, multivariate analysis was applied. Chi-squared Test confirmed the reliability of the analysis, according to $p < 0.001$ (Table 6). The loading values of the climatic parameters (as factors) in relation to the principal components were obtained (Table 7, Figure 8).

Table 6. Chi-squared Test results

	Value	Df	p
Temperature			
Model	512.948	23	< .001
Rainfall			
Model	1118.988	15	< .001

Table 7. Factors loadings

Table 7: Factors loadings														
	Temperature							Rainfall						
	PC1	PC2	PC3	PC4	PC5	Unique- ness		PC1	PC2	PC3	PC4	PC5	PC6	Unique- ness
VIII	0.734					0.364	Amount P	0.874						0.028
V	0.730					0.346	VIII	0.713						0.368
II		0.832				0.225	II	0.532						0.403
III		0.812				0.305	I		0.822					0.223
Mean T		0.642				0.017	V		0.776					0.306
X			0.799			0.287	IX			0.716				0.355
IV			0.689			0.313	VII			0.607				0.449
IX				0.863		0.229	XI			-0.548				0.394
XI					0.676	0.305	XII				0.840			0.285
I					-0.672	0.242	X					-0.739		0.291
VI						0.389	III					0.715		0.282
VII						0.428	IV						0.847	0.221
XII						0.436	VI						-0.504	0.419

In the case of temperature, the multivariate analysis generated five principal components in which thermal parameters (monthly, and Mean T) were loaded, with the contribution value, on each component. Monthly thermal parameters and Mean T showed positive action in relation to the principal components, except for the thermal parameter in January which showed negative action in PC5.

In the case of rainfall, six principal components resulted, in which climatic parameters represented by precipitation (monthly, and Amount P) were loaded with the contribution values on each component.

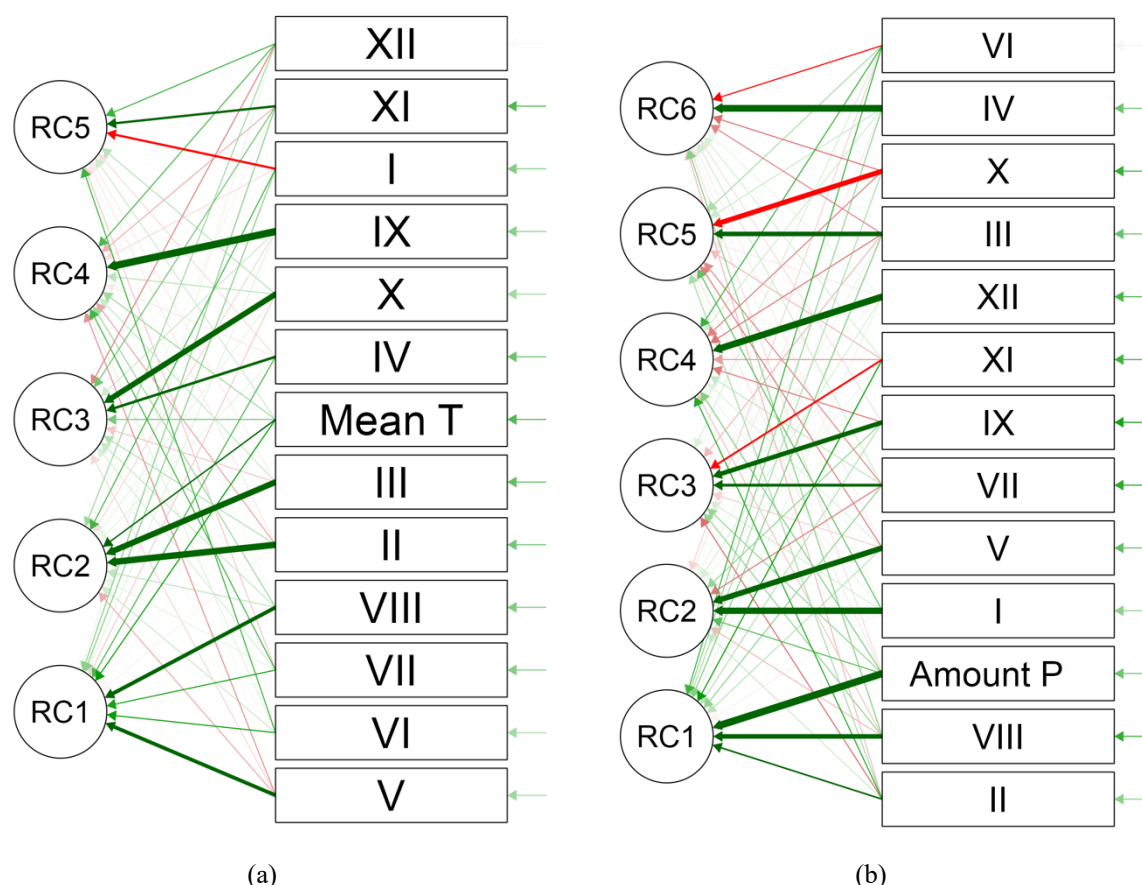


Figure 8. Distribution diagram of climatic factors in relation to the main components (a) – Temperature, (b) – Precipitation

Precipitation, as a climatic parameter, presented a positive action in most cases, except for the month of November with a negative action in PC3 ($r = -0.548$), the month of October with a negative action in PC5 ($r = -0.739$), and the month of June with a negative action in PC6 ($r = -0.504$), Table 7, Figure 8. The characteristics of the components are presented in Table 8.

Table 8. Component characteristics

Components	Unrotated solution			Rotated solution			Components	Unrotated solution			Rotated solution		
	Eigenvalue	Proportion var.	Cumulative	SumSq. Loadings	Proportion var.	Cumulative		Eigenvalue	Proportion var.	Cumulative	SumSq. Loadings	Proportion var.	Cumulative
Component 1	3.389	0.261	0.261	2.546	0.196	0.196	Component 1	2.423	0.186	0.186	2.156	0.166	0.166
Component 2	1.926	0.148	0.409	2.129	0.164	0.360	Component 2	1.619	0.125	0.311	1.531	0.118	0.284
Component 3	1.379	0.106	0.515	1.538	0.118	0.478	Component 3	1.382	0.106	0.417	1.381	0.106	0.390
Component 4	1.297	0.100	0.615	1.469	0.113	0.591	Component 4	1.248	0.096	0.513	1.360	0.105	0.494
Component 5	1.122	0.086	0.701	1.430	0.110	0.701	Component 5	1.171	0.090	0.603	1.350	0.104	0.598
							Component 6	1.134	0.087	0.690	1.197	0.092	0.690

Multivariate analysis based on the annual mean values of temperatures and precipitation, recorded during the study period, led to the PCA diagram (Figure 9). The principal components fully explained the variance in the analyzed data set. It was observed that some years were positioned correlated with the thermal regime (e.g. 2002, 2008, 2019) and with the annual amount of precipitation (e.g. 1979, 2001, 2010).

Some of the years were positioned intermediately (e.g. 2007, 2013, 2014), and some of the years were positioned independently (e.g. 1973, 1080, 1984). The year 2000 was the year with the extreme deficit of the

pluviometric regime during the study period, and it was positioned independently, and outside the 95% confidence interval (Figure 9).

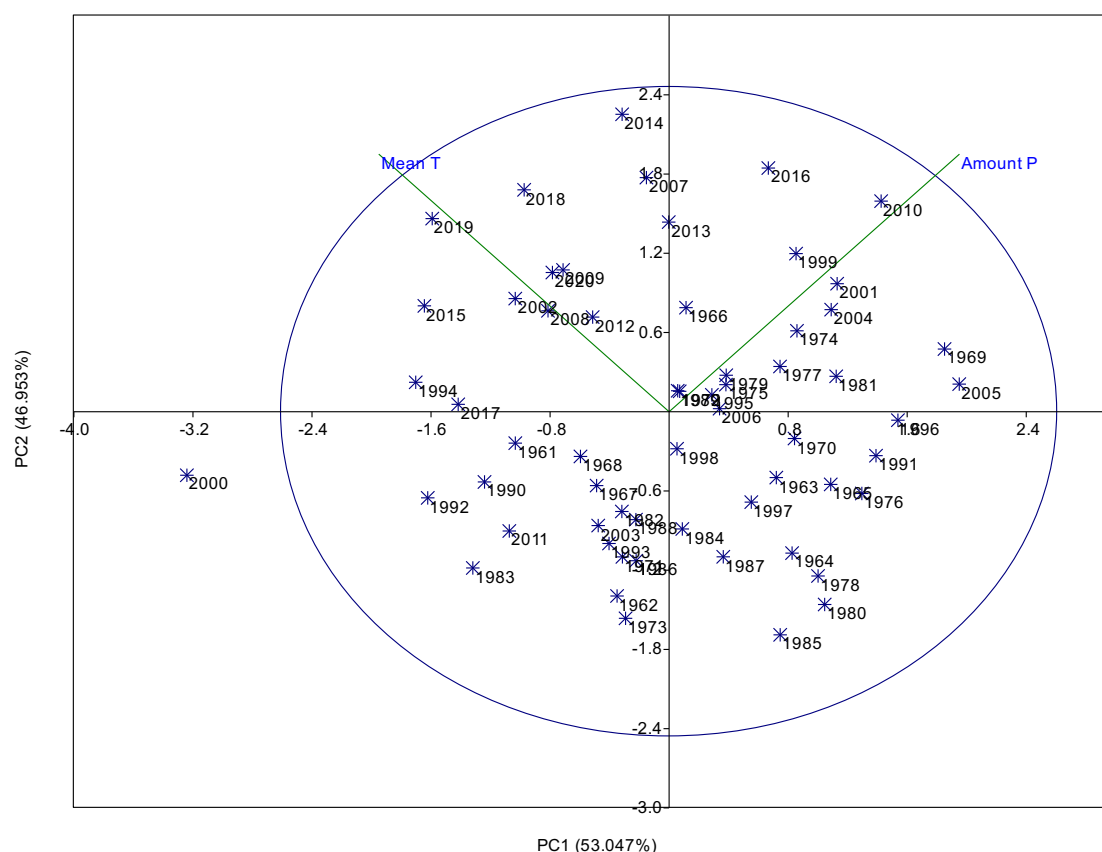


Figure 9. PCA diagram, with the distribution of years in relation to climatic parameters

The cluster analysis generated the association of years in clusters based on similarity in relation to the values of the climatic parameters analyzed concurrently (T °C, P mm), under conditions of $Coph.corr. = 0.739$ (Figure 10). The year 2000 positioned itself independently, with extreme values in terms of the pluviometric regime, during the study period. The other years were grouped based on similarity, in three distinct subclusters.

Subcluster C2-1 (left of the dendrogram) included 21 years, characterized by low rainfall, with an average value of $\bar{P}_{(C2-1)} = 456.71$ mm, below the average for the study period ($\bar{P} = 564.54$ mm). Subcluster C2-2 (middle of the dendrogram) included 16 years, characterized mainly by high rainfall, with an average value of $\bar{P}_{(C2-2)} = 702.44$ mm (above the average for the study period). Subcluster C2-3 (right of the dendrogram) included 22 years with intermediate rainfall, with an average value of the subcluster $\bar{P}_{(C2-3)} = 573.96$ mm, close to the average value for the study period.

In relation to the thermal regime, the descriptive statistical analysis generated the threshold values of the quartiles, according to Table 1. Based on the annual mean of temperature values, the years considered in the study were grouped into quartiles (Figure 11).

The average temperature value calculated for each quartile recorded the values $\bar{T}_{(Q1)} = 9.95$ °C (Lower quartile), $\bar{T}_{(Q2)} = 10.60$ °C, $\bar{T}_{(Q3)} = 11.07$ °C (Median quartiles), and $\bar{T}_{(Q4)} = 12.06$ °C (Upper quartile), respectively.

The variation of climatic parameters (T °C, and P mm) during the study period was expressed by sinusoidal models, with the properties in Table 9, and the graphical distribution in Figure 12. In the case of temperature variation, a sinusoidal model resulted in statistical safety, with $R^2 = 0.581$ and a confidence level $p = 0.00026$. In the case of rainfall variation, the resulting sinusoidal model presented $R^2 = 0.247$, with $p = 0.5955$.

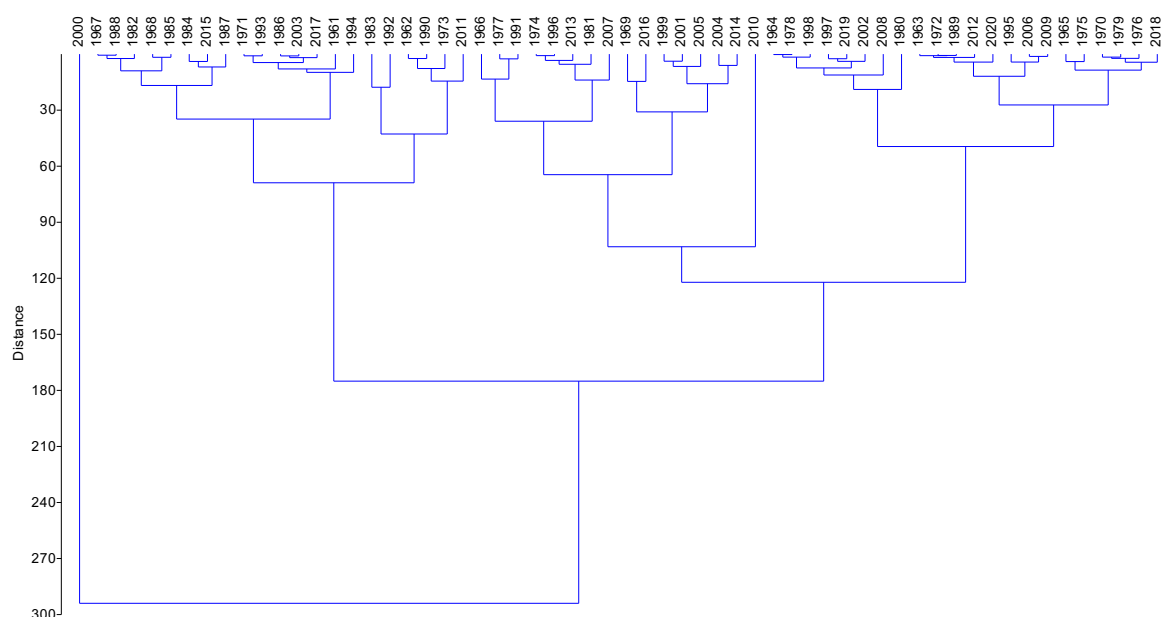


Figure 10. Cluster dendrogram with year association based on Euclidean distances

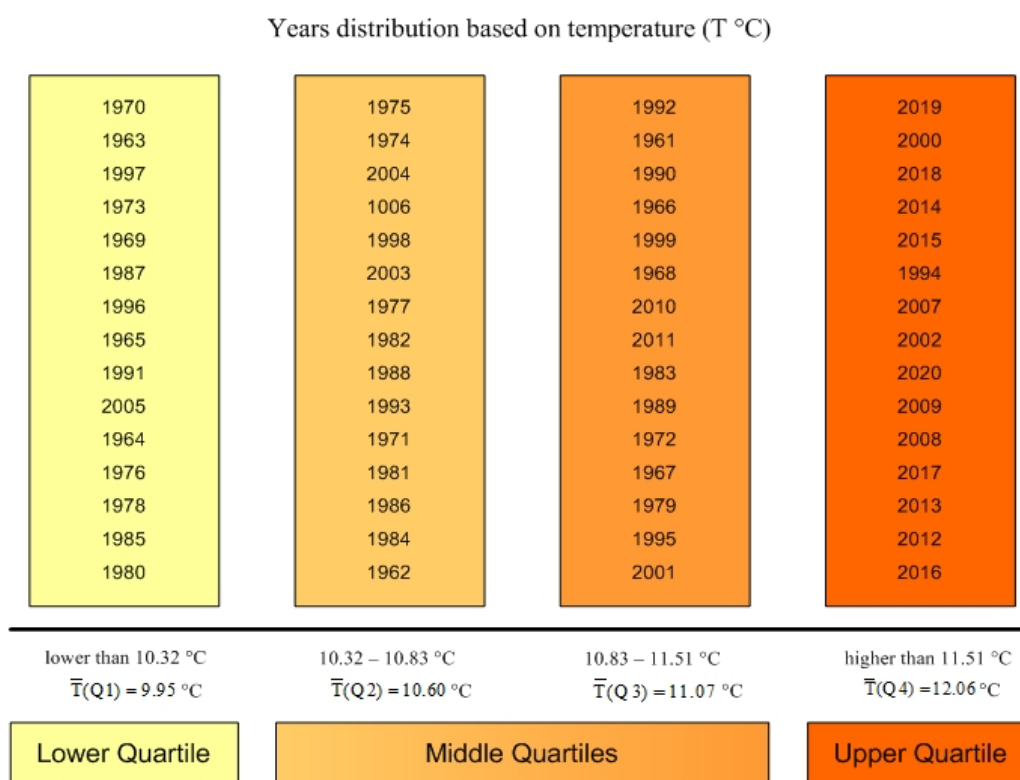
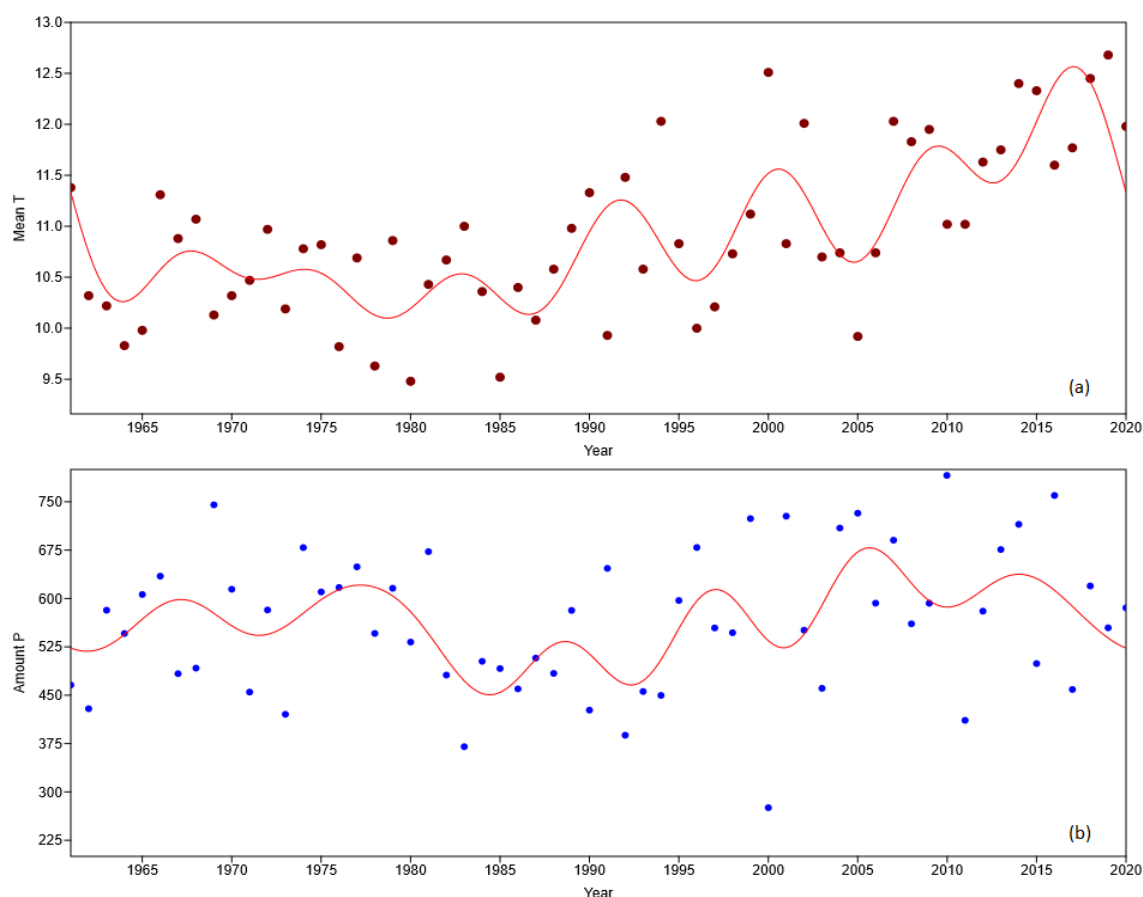


Figure 11. Classification of study years into quartiles, in relation to the average annual temperature value

The sinusoidal model for temperature variation ($p = 0.00026$) showed an increasing trend over the study period, more accelerated in the period 1990 – 2020. For the entire data set (1961 – 2020) Mann-Kendall trend Test confirmed the increasing trend of temperature variation over the study period, with parameters $S = 712$, $Z = 4.5353$, $p < 0.001$ ($p = 5.7532 \times 10^{-6}$). For the data set, period 1990 – 2020, Mann-Kendall trend Test also confirmed the increasing trend of temperature variation, with parameters $S = 183$, $Z = 3.0951$, $p = 0.0019$.

Table 9. The values of the statistical parameters of the sinusoidal models for temperature and precipitation during the study period

Parameter	Temperature			Precipitation		
	Amplitude	Phase	Period	Amplitude	Phase	Period
1	0.6501	-1.005	59.00	41.96	-0.641	59.00
2	0.2319	-0.855	29.50	40.84	-3.124	29.50
3	0.2631	-1.666	19.67	14.79	-1.859	19.67
4	0.1972	-1.570	14.75	10.96	1.291	14.75
5	0.1447	-1.926	11.80	14.94	-3.13	11.80
6	0.1916	-0.463	9.83	35.6	-2.35	9.83
7	0.3471	-2.027	8.43	21.95	1.712	8.43
8	0.0334	-2.478	7.38	13	-0.78	7.38
Offset		10.910			565.200	
Chi-sq		16.379			5.36E+05	
Akaike		61.030			5.36E+05	
R ²		0.581			0.247	
p		0.00026			0.59554	

**Figure 12.** Sinusoidal patterns of temperature (a) and precipitation (b) variation over the study period

The graphical representation of the temperature variation trend over the entire study interval, and in the sub-interval 1990 – 2020, with the confidence interval, is presented in Figure 13 (a), respectively Figure 13 (b), with the distribution of residual values in Figure 14. In the case of precipitation, the Mann-Kendall trend Test indicated there is no statistically significant trend, with parameters $S = 224$, $Z = 1.4223$, $p = 0.1549$.

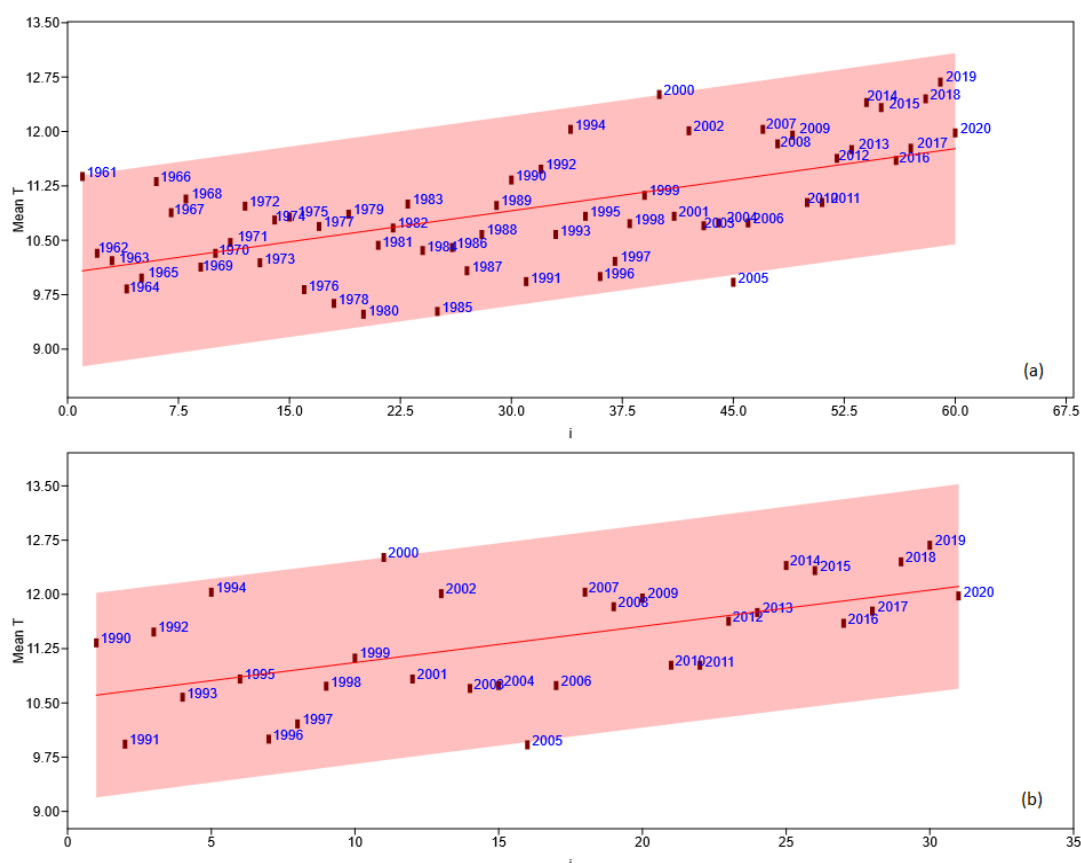


Figure 13. Temperature distribution trend, for the entire study interval (a), and for the period 1990 – 2020 (b)

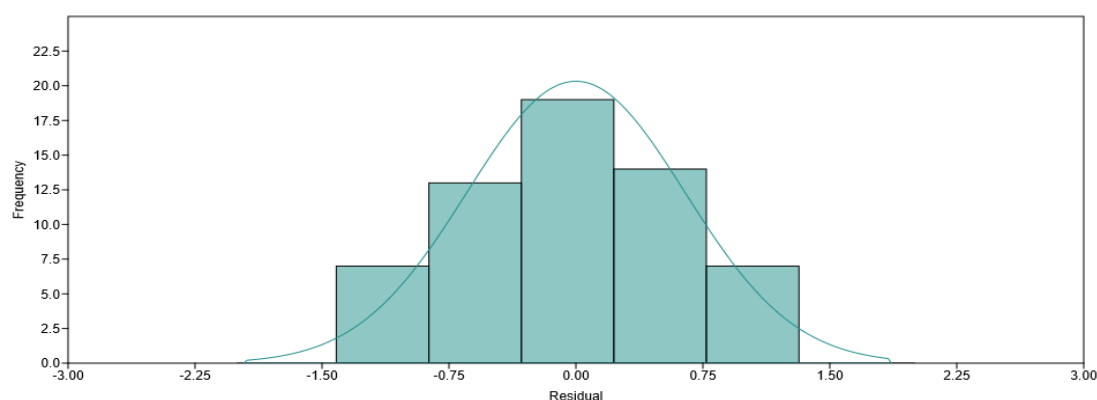


Figure 14. Graphical distribution of residual values, for the temperature variation model

The average annual temperature during the study period varied between $T = 9.48\text{ }^{\circ}\text{C}$ (year 1980) and $T = 12.68\text{ }^{\circ}\text{C}$ (year 2019). In relation to the multiannual mean temperature during the study period ($\bar{T} = 10.92\text{ }^{\circ}\text{C}$), a wider variation was observed, with values frequently below the multiannual average in the first three decades of the study interval (1961 – 1990), compared to the last three decades.

In the first half of the study period, 21 years had annual mean temperatures below the multi-year average, five years had annual mean temperatures above the multi-year average, and four years had values very close to the multi-year average. In the second half of the study period, 11 years had values below the multi-year average, 17 years had values above the multi-year average, and two years had values very close to the multi-year average. In the last decade of the study period (2011–2020), two years had annual mean temperatures at the multi-year average, and eight years had annual mean temperatures above the multi-year average.

In the case of precipitation, the annual amount of precipitation, during the study period, presented values ranging between $P = 275.5\text{ mm}$ (year 2000) and $P = 799.10\text{ mm}$ (year 2010). In relation to the multiannual

average for the study period ($\bar{P} = 564.54$ mm), the year 2000 recorded the highest rainfall deficit (275.5 mm). During the study period, other years with obvious precipitation deficit were observed, namely the years 1962, 1973, 1983, 1992, 2011.

Decreases of up to 60 mm of precipitation (total annual precipitation) per decade have been reported in the analysis of precipitation patterns for the Mediterranean area (Yavaşlı, 2025). Distortions have been recorded in drought simulation models regarding the frequency, duration and intensity of drought climate phenomena (Cheung et al., 2025). Large time intervals of climate data have been divided into shorter periods to better capture trends in climate change and manifestation, temperature and precipitation (Pavan Kumar et al., 2025). The existence of similar patterns of climatic manifestation has been identified over short time intervals (e.g. quarterly), within long-term recorded climatic data (Pavan Kumar et al., 2025).

In the case of thermal values, the model describing the temperature variation presented statistical certainty at the $p=0.00026$ level, with $R^2 = 0.581$. In the case of precipitation, based on the entire series of values (1961 - 2020), the variation model resulting from the analysis did not present statistical certainty ($p=0.595$).

CONCLUSIONS

The applied mathematical and statistical analysis methods and tests described the variation of the values of the climatic parameters (temperature, precipitation) during the study period, the level of similarity between years, their differences and significance compared to the calculated multiannual average values, and the positioning of the climatic parameters in relation to the principal components. The data series presented statistical reliability, according to the ANOVA Test.

The average value calculated over the study period for temperature was $\bar{T} = 10.92 \pm 0.11$ °C, and the average value calculated for precipitation was $\bar{P} = 564.54 \pm 14.17$ mm. In relation to the average values calculated, years with significant differences were recorded for both temperature and precipitation. In 1980, the average annual temperature value $T = 9.48$ °C was recorded (the lowest in the study interval), and in 2019 the average annual temperature value $T = 12.68$ °C was recorded (the highest in the study interval). In terms of precipitation, the lowest level of precipitation was recorded in 2000 ($P = 275.50$ mm), and the highest level of precipitation was recorded in 2010 ($P = 799.10$ mm).

The frequency of warm years (with thermal values above the calculated multiannual average) increased during the study period. In the first half of the period (1961 – 1990) only three years (1961, 1966 and 1990) presented thermal values above the multiannual average, in conditions of statistical safety ($p < 0.001$, ***). In the second half of the period (1991 – 2020) in 16 years thermal values above the multiannual average were recorded, in conditions of statistical safety. In the decade 1991 – 2000 three years presented thermal values above the multiannual average (1992, 1994, 2000); In the decade 2001 – 2010 four years presented thermal values above the multiannual average (2002, 2007, 2008 and 2009); in the decade 2011 - 2020, nine consecutive years presented thermal values above the multiannual average (2012 - 2020).

Multivariate analysis (PCA) led to the classification of the monthly calendar periods (I to XII), the mean temperature (Mean T, °C) and the amount of precipitation (Amount P, mm) as factors, in relation to the principal components ($p < 0.001$). The results obtained (Numerical values, diagrams) showed the positioning of each factor in the principal components, the mode and intensity of action. Cluster analysis completed the set of results with the dendrogram of grouping the years based on similarity, in relation to the values of the climatic parameters. The hierarchy of the years was made in quartiles, in relation to the values of the climatic parameters and the delimitation thresholds.

The variation of climatic data, temperature and precipitation, over the entire study interval, was described by sigmoidal models, under different conditions of statistical certainty ($p = 0.00026$ for temperature; $p = 0.595$ for precipitation). The results of the models showed the obvious trend of increasing average annual temperatures in the last two decades of the study period, and a fluctuating variation in precipitation levels, with pronounced drought periods, which generate negative effects on agricultural crops.

ACKNOWLEDGMENTS

The authors thank the ULS “King Mihai I” from Timisoara for facilitating this study.

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