Air temperature trend analysis of Târgu Mureș, Romania, between 1986-2020

Ion BUGLEA[1*]
[1]Department of Geography, University of Oradea, Romania

*Correspondence to: Ion BUGLEA. E-mail: bugle9@hotmail.com.

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ABSTRACT: One of the processes with the greatest impact on humanity in the second half of the twentieth century was global warming. Detection, estimation and prediction of trends are important aspects of climate research (Hansen and Lebedeff, 1987). Trends have become the most frequently used technique to identify climatic variability on a regional and local basis (Amadi et. al., 2014). Trend is a long-term change (increase or decrease) in a time series (Ragatoa, 2018). In the current context of climate change, we considered that a study on the evolution of air temperature in the last 35 years is needed, especially since it is the first study of its kind for this area. The aim of this study was to highlight long-term trends (magnitude and direction) in terms of air temperature (average, minimum, maximum, anomalies), at different time scales (multiannual, seasonal and monthly), in the city of Târgu Mureș, between 1986-2020. The analyzed data series come from the archive of the National Meteorological Administration with the records made by the local meteorological station. The analysis was performed using MS Excel spreadsheets with MAKESENS software to evaluate trend and data distribution (Mann-Kendall, Sen's slope, Kurtosis and Skewness). According to the results of the Mann-Kendall test and the estimation of the slope of Sen, there were statistically significant positive trends in the warmer months (June, July and August). Average temperature values increased by up to 1.6° C, and the average slope varied by 0.049° C / 35 years. Regarding the multiannual average, with one exception (2011), the last 13 years have shown positive trends. Consequently, the average annual temperature in Târgu Mureș shows obvious growth trends in the last 35 years.

KEY WORDS: Trend, MAKESENS, Mann-Kendall, Sen's slope estimator, average.

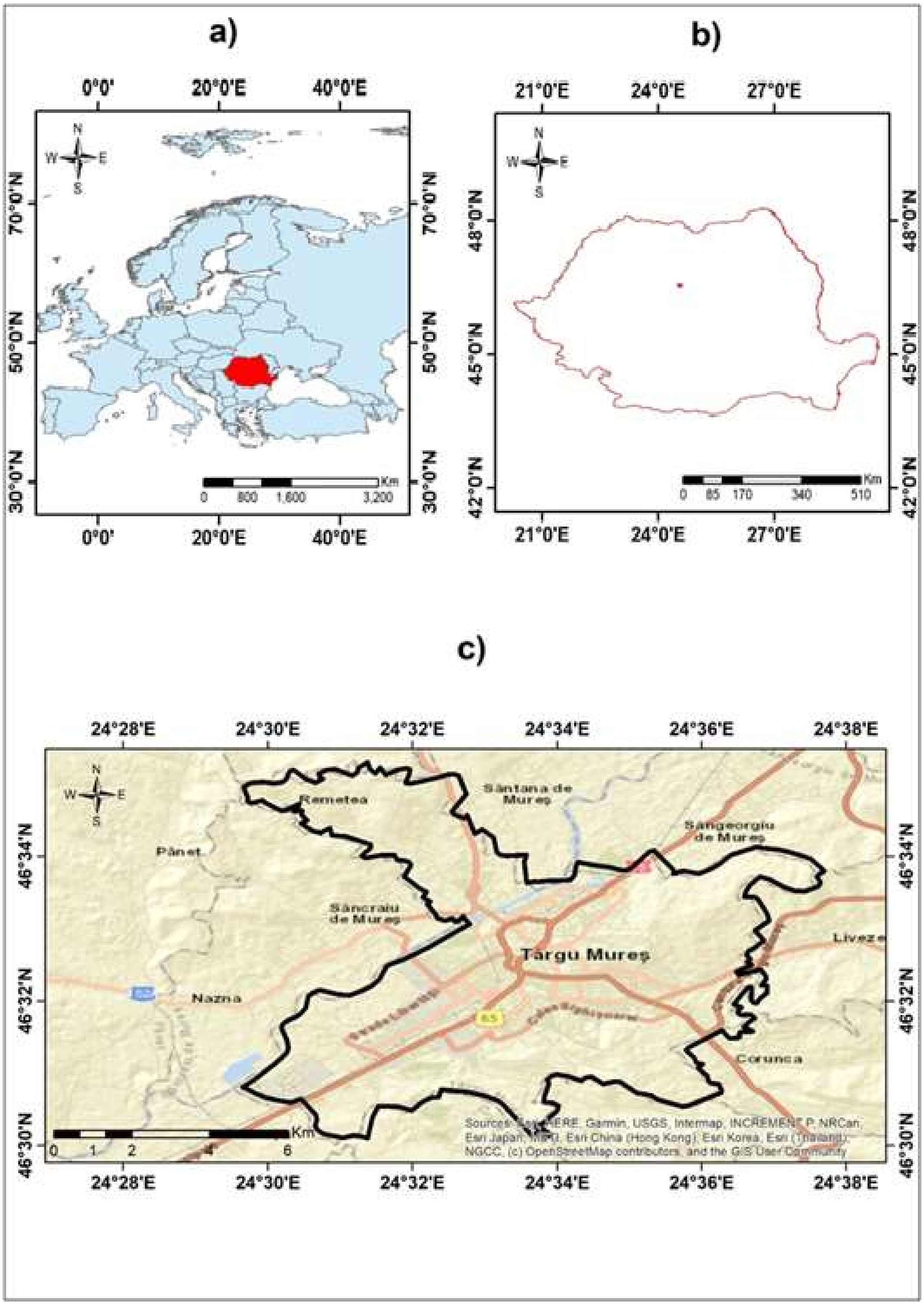
1. Introduction

Air temperature is one of the most important variables in climatology along with precipitation, pressure, wind, with an appreciable influence on the environment and implicitly on humans. Being an element with a marked climatic variability, both spatial and temporal at all local, regional and

global scales, long-term analysis is fundamental in understanding climate variability. The global and continental level of climate analysis have been very useful in understanding the phenomena of large-scale change, but they are less useful for local to regional planning (Shi and Xu 2008). Climate change that may occur on a global scale may not reflect changes that may occur on a regional scale (Martinez et al. 2012). Even small changes in air temperature variations can cause considerable changes in the variability and / or severity of extreme events (Hennessy and Pittock, 1995). The increase in average temperature in the last century has been largely demonstrated and presented in many studies focused on different regions of the world (Croitoru and Piticar, 2014). According to the analyzes of specialists from NASA's Goddard Institute for Space Studies (GISS), the average global temperature on Earth has risen just over 1° Celsius since 1880. (https://earthobservatory.nasa.gov/world-of-change/decadaltemp.php). In Europe, between 1950 and 2010, the average warming trend was 0.18° C/decade (www.cru.uea.ac.uk/cru/data/temperature). Numerous studies have concluded that the entire European continent has experienced an obvious warming trend. According to Intergovernmental Panel on Climate Change (IPCC 2007b, p. 545), the heating was more evident in winter than in summer. For Romania, a heating of approximately 0.5° C has been estimated since 1901 for the average annual temperatures (Anders et al. 2014). Long-term analyzes of meteorological variables are essential for monitoring ongoing climate change. By determining trends, it is likely to establish the predominant direction of the given numerical variables. In a series of chronological data between 1986-2020, the direction of the specific variable is represented, which in our case is the air temperature in the city of Târgu Mureș. The aim of this study is to present the possible trends of the multiannual, seasonal and monthly average air temperatures for the time series of 35 years, in the city of Târgu Mureș. In addition, the objectives of this study are:
i) analysis of the multiannual temperature regime;
ii) analysis of the seasonal temperature regime;
iii) analysis of the monthly temperature regime.
Detection of trends in time series of air temperatures is representative for estimating the impact on the environment and human health. The results of this study come to complete the understanding of regional temperature variability in recent decades in Târgu Mureș, for decision makers in developing strategies to adapt and mitigate the effects of climate change.

2. Study area

Târgu Mureș is located in the center of Romania, in the Transylvanian depression, at an altitude of 308 m. The geographical location is 46° 32 'N and lon. 24° 32 'E, with an area of 66.96 square kilometers. The climate of the city is temperate-continental transition, specific to the geographical position, influenced by the local topography and the specifics of the atmosphere dynamics. Köppen's climate classification is 'Dfb' (continental hot summer climate), which is characterized by warm summers and frosty winters, which means that the temperature difference between summer and winter is large. Here are felt both the western influences of the Atlantic Ocean and those of the east of Russia. The average annual temperature in Târgu Mureș was 9.3° C for the reference period 1961-1990.



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Figure 1 Location of (a) Romania in Europe, (b) Târgu Mureș in Romania, (c) city area.

3. Methods

For this analysis, the observation data recorded at the local meteorological station Târgu Mureș in the last 35 years were used. The average multiannual temperature in the studied range was 9.3° C, a value against which the meaning and value of deviations can be determined. Temperature data come from the archives of the National Meteorological Administration (ANM). Statistical and mathematical methods were used to show the trends of the temperature series. These are classified into parametric and nonparametric methods (Chen et al. 2007). Nonparametric methods were used in the present study. These values were calculated in Excel spreadsheets with MAKESENS software (Mann-Kendall test for trends and estimates of Sen's slope), developed by researchers at the Finnish Meteorological Institute (Salmi et al., 2002). The average daily air temperature is the basic indicator in climatological calculations. Daily air temperature values were transformed into monthly averages. The average monthly air temperatures were ordered according to the four seasons: winter (December-January-February), spring (March-April-May), summer (June-July-August) and autumn (September-October-November) to could reproduce possible trends. The minimum classical period defined by the World Meteorological Organization to be able to evaluate a long-term temperature trend is 30 years. In our case, the period of analysis and comparison on a multiannual scale was 35 years. These methods, which are used here in their basic forms, are widely used to detect changes in climatic data series because it is robust to outliers and does not assume an underlying probability distribution of the data series (Moberg et al., 2002). In order to highlight the trend and variation of the data compared to the average, the analysis structure from (Figure 2) was used.

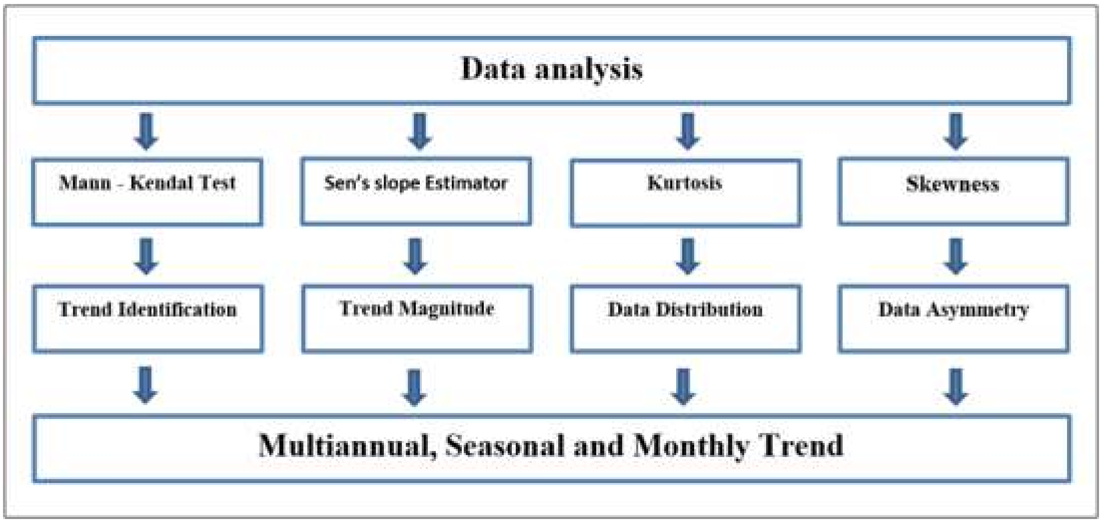


Figure 2 Trend analysis structure.

3.1. Mann - Kendal Test

The World Meteorological Organization (WMO), has suggested the Mann-Kendall test for assessing the temporal trends in the time series of environmental data (P. Shi, X. Ma, X. Chen, S. Qu, Z. Zhang, 2013). In Romania, the same method and software have also been used with good results to identify trends in different data series: temperature, precipitations, fog, snow cover (Micu and Micu, 2006; Holobaca et al., 2008; Micu, 2009; Mureşan and Croitoru, 2009; Croitoru et al. 2011 a, b, c). Mann-Kendall test is a nonparametric test that is widely used in the field of climatological time series and shows the significance of trends in data series (Martinez et al., 2012). The Mann-Kendall (Mann, 1945; Kendall, 1975) Z statistics is calculated mathematically as follows:

$$Z = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_{j-} x_i) \qquad (1)$$

where:

n = length of the data

x_j, x_i = sequential data values

sgn = signum function

The presence of a statistically significant trend was assessed using the Z value. An upward (increasing) or downward (decreasing) trend is given by a positive or negative value of Z. A major advantage of this test is that it has a low sensitivity to unexpected interruptions induced by time series inhomogeneity.

3.2. Sen's slope estimator

The presence of a linear trend in a time series can be estimated using a simple nonparametric procedure developed by Sen, 1968. The magnitude of the trend is calculated by the Sen's estimator. True slope (Q) is calculated mathematically as follows:

$$Q = \frac{x_j - x_k}{j-k} \text{ for i = 1,2,3,...,N} \qquad (2)$$

where x_j and x_k = data values at time
j and k respectively where j > k

The advantage of this method is that it allows missing values and data series do not have to follow a specific distribution.

3.3. Kurtosis

A statistical method that is used to calculate the distribution of data around average values. The maximum distribution indicates peaks being represented by positive values of K, and the flat distribution is represented by negative values. The normal distribution is indicated by a null value. The value of Kurtosis (K) is calculated mathematically as follows:

$$K = \frac{\sum_{i=1}^{N} (Xi - \bar{X})^4}{(N-1)s^4} - 3 \qquad (3)$$

where: N = sample size
X_i = individual score
$\bar{X}$ = mean
s = standard-deviation

3.4. Skewness

The Skewness coefficient is used to determine the asymmetry in the distribution of data compared to the mean. The value of Kurtosis (S) is calculated mathematically as follows:

$$S = \frac{\sum_{i=1}^{N} (Xi-\bar{X})^3}{(N-1)s^3} \tag{4}$$

where: N = sample size

X_i = individual score

$\bar{X}$ = mean

s = standard-deviation

According to Bulmer (1979), if S is less than -1 or higher +1, the distribution is highly skewed; if S is between -/+1and -/+1/2, the distribution is moderately skewed, while values between -1/2 and +1/2 indicate an approximately symmetrical distribution.

4. Results and discussion

The analysis was performed using MS Excel spreadsheets with MAKESENS software to evaluate possible temperature trends. The data analysis was performed to highlight the statistical parameters (mean, min-max temperature, standard deviation, coefficient of variation, Mann-Kendal statistics, significance, Sen's Slope, skewness, kurtosis) to identify the positive or negative trend in the time series of temperature range for the period 1986-2020. In (Table 1), each parameter was analyzed in detail.

4.1. Multiannual temperature regime of the annual average

The peculiarities of the underlying active surface, the altitude differences between the Mureș meadow and the nearby hills, the height and density of the buildings, the presence of some industrial objectives, determine variations of the multiannual average air temperature in the Târgu Mureș area.

The average multiannual temperatures, calculated using values from 1986-2020, are 9.6° C in Târgu Mureș. According to the linear regression model, in our case the slope of the regression line is positive, with the value of 0.049° C / 35 years for the period 1986-2020. The lowest average air temperatures were 8.16° C (1993) and the highest 11.02° C (2019), (Figure 3-a), with an average amplitude of 2.8° C. The graphical representation indicates an alternation of cold and warm periods, with a colder period recorded between 1993 by 8.1° C and 2005 by 8.6° C. A significant increase in the frequency of warm years can be observed in the last decade of the study period, when the average annual temperature exceeded the average of the multiannual temperature by more than 1° C. The results of the statistical analysis of the multiannual average temperature are presented in (Table 1) and indicate α=0.001 level of significance. The analysis of the deviations of the average annual temperatures from the multiannual average, presents the values of the positive deviation with variations between + 0.1° C and + 1.7° C (Figure 3-b). The years with positive thermal deviations from the multiannual average represent 57.14 %. Positive deviation values that exceeded 1° C were calculated for the years 2007 (+ 1.1° C), 2009 (+ 1.2° C), 2014 (+ 1.4° C), 2015 (+ 1.1° C), 2018 (+ 1.6° C), 2019 (+ 1.7° C), 2020 (+ 1.2° C). The years with negative thermal deviations from the multiannual average represent 37.14 %, with deviation values between (- 0.1° C) in 2004 and (- 0.9° C) in 1997. The largest positive deviation was recorded in 2019 (+ 1.7° C) and the lowest in 1993 and 1997 (-

0.9° C). There were years without positive or negative deviations in 1986 and 1988. The minimum annual temperature for the study area ranged from (- 7.5° C) in 2001 to (+ 0.7° C) in 2014, and the average annual minimum temperature was (- 3.6° C). The proportion of variation of the minimum annual temperature was 37.14%. The minimum annual temperature showed a statistically positive trend with a factor of + 0.03° C / 35 years (Figure 3-c). The maximum annual temperature for the study area varied from (+ 18.7° C) in 1997 to (+ 24.8° C) in 2012, and the average maximum annual temperature was 24.8° C. The proportion of variation of the minimum annual temperature was 57.14%. The maximum annual temperature showed a statistically positive trend with a factor of + 0.03° C / 35 years (Figure 3-d). There is a slight dominance of the years with a positive average thermal deviation compared to the multiannual average of 9.3° C. The trend reveals an increase in the maximum annual averages in frequency and amplitude.

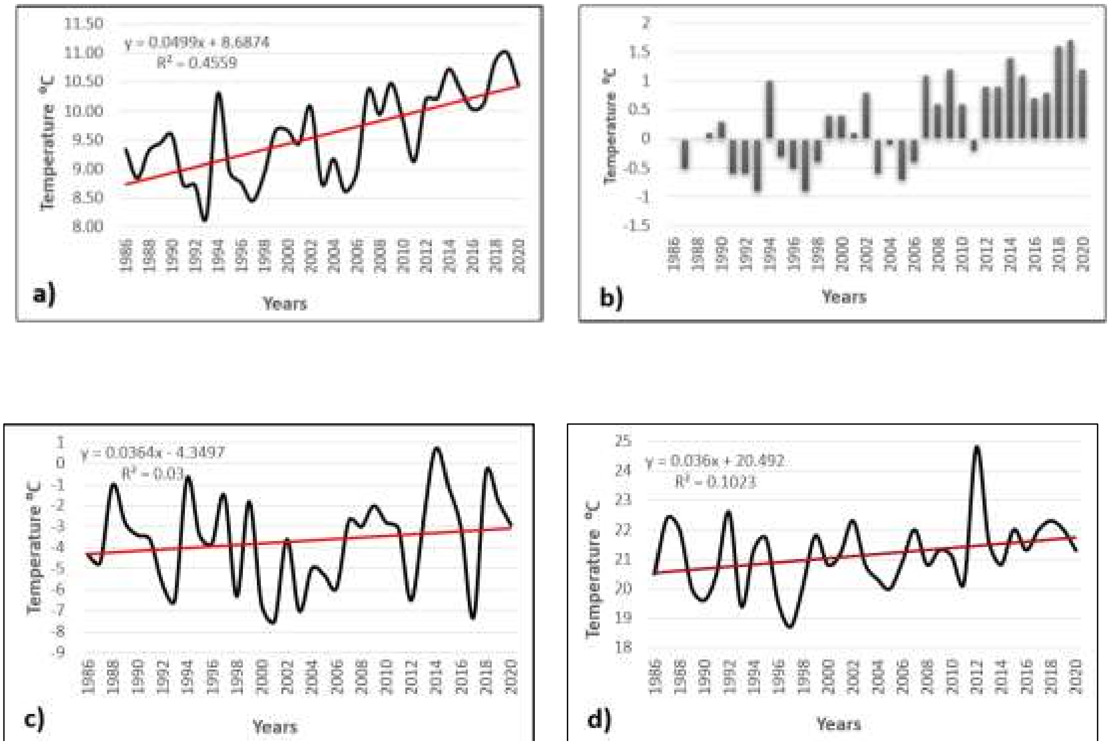


Figure 3 Multiannual temperature regime between 1986-2020 in Târgu Mureș: a) average, b) deviation, c) minimum temperature, d) maximum temperature.

4.2. Seasonal analysis of the multiannual average temperature

For the analysis of seasonal trends, the monthly average temperature values were grouped into four seasons: spring (March-April-May), summer (June-July-August), autumn (September-October November) and winter (December-January-February). The evolution of temperatures indicates positive trends in all four seasons. The average spring temperature for the studied period was 10.2° C, with temperature variations from a low of (+ 7.7° C) in 1987 to a high of (+ 12.3° C) in 2018. The average annual temperature showed a statistically positive trend with a factor of + 0.03° C / 35 years (Figure 4-b). Summer is characterized by an obvious upward trend, the level of significance reaching 0.001 (Figure 4-c, Table 1). The average summer temperature for the studied period was 19.9° C, with temperature variations from a low of (+ 17.2° C) in 1988 to a high of (+ 24.8° C) in 2012. Average summer temperature for the reference period 1961-1990 was 18.8° C (Clima României, 2008) and the average summer temperature for the studied period 1986-2020 was 19.9° C. Average temperature annual showed a statistically positive trend with a factor of + 0.05° C / 35 years. The autumn season shows an upward trend, the significance level reaching 0.01 (Figure 4-d, Table 1). The average temperature in the autumn season for the studied period was 19.9° C, the temperature ranged from a low of (-1° C) in 1988 to a high of (+ 18.6° C) in 1994. The average temperature annual showed an increasing trend, with a factor of + 0.05° C / 35 years. Winter shows an upward trend, the level of significance reaching 0.05 (Figure 4, Table 1). The average temperature in the winter season for the studied period was (- 1.3° C), the temperature varied from a minimum of (- 7.5° C) in 2001 to a maximum of (+ 4.5° C) in 2016.

The average winter temperature for the reference period 1961-1990 was (- 2.2° C) (Clima României, 2008), and the average winter temperature for the studied period 1986-2020 was (- 1.3° C). The average annual temperature showed an upward trend, with a factor of + 0.04° C / 35 years. In all four seasons, the average temperature trend is positive, but the summer season is noticeable when the warming trend is much accentuated.

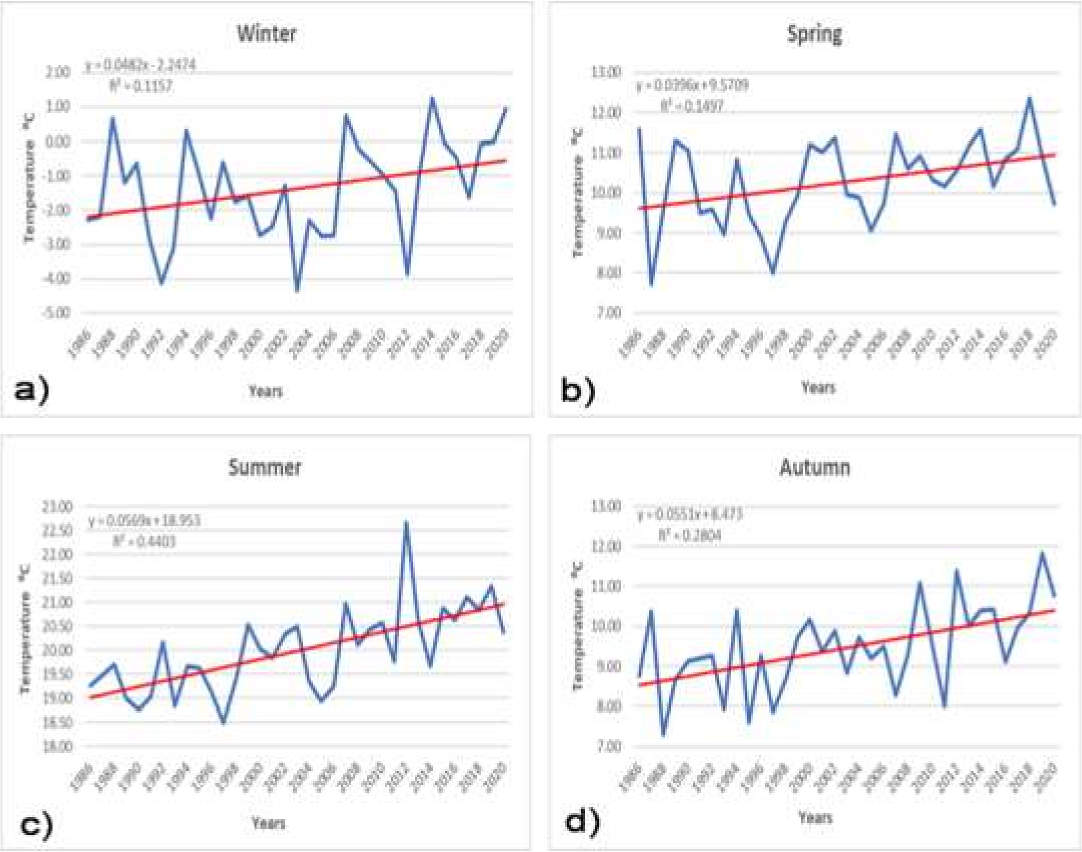
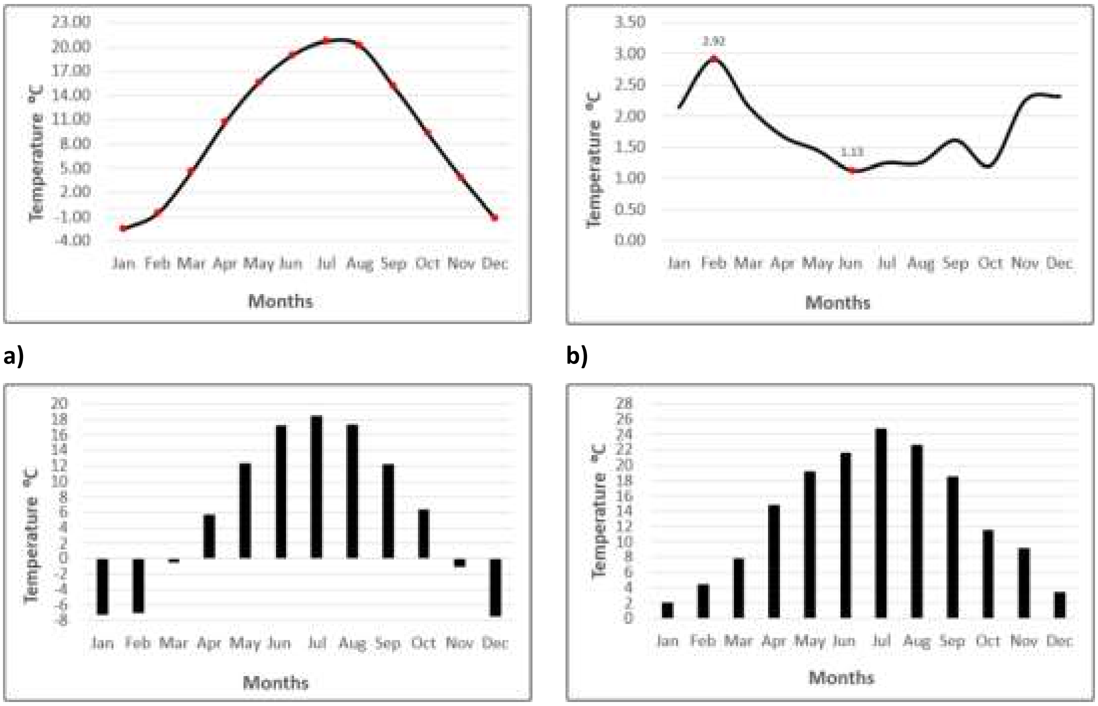


Figure 4 The multiannual trend of seasonal average temperatures between 1986-2020 in Târgu Mureș.

4.3. Multiannual monthly average temperature regime

The average monthly temperature varies in relation to the amount of solar energy that the Earth's surface receives during a year. The average monthly temperature fluctuates according to an annual pattern, with an increase in temperature starting in January, when it records the lowest monthly thermal average (- 2.5° C), until July, which marks the maximum value of the average monthly temperature (+ 20.7° C), resulting a monthly amplitude of 23.2° C. After that, the average monthly air temperature curve decreases by the end of the year (Figure 5-a).



a) **b)**

c) **d)**

Figure 5 Monthly temperatures variation between 1986-2020 in Târgu Mureș: a) average b) deviation, c) minimum temperature, d) maximum temperature.

The analysis of the thermal differences between the months of the year shows that the transition of the average values of the air temperature from one month to another is done gradually during the summer and in the winter months with differences of (1-2° C), but in the transition months spring-autumn thermal contrasts are much more obvious with differences of over 5° C (Table 1). All 12 months display positive Z values, highlighting upward trends. The most important increase is characteristic of the summer months of June (Z=3.627) and August (Z=3.370), which show statistically significant positive slopes α = 0.001. In September the slope is positive, statistically significant (Z=2.148), with a value α = 0.05, having 95% significance interval. The other months show positive Z values, but the trends are not statistically significant. The minimum monthly average in January and the maximum in July are the consequences of the minimum and maximum radiative balance of these months, respectively. In January, the incident solar radiation is higher than in December, but the penetration of cold and dry air due to the ridge of the Siberian anticyclone, favors

the formation of thermal inversions and more accentuated radiative cooling. The multiannual monthly average of January for the studied period was (- 2.5° C).
The lowest value of the multiannual thermal average of January for the studied period in Târgu Mureș was (- 7.3° C) in 2017. Although the maximum of incident solar radiation occurs in June, the average monthly maximum is recorded in July , the main causes being the lower relative humidity and the higher period of the Sun's brightness this month, determining the accentuated heating of the active surface. The highest value of the multiannual thermal average of July for the studied period, in Târgu Mureș was (+ 24.8° C) in 2012.

The monthly anomalies for the period 1986-2020, as can be seen in (Figure 5-b, Table 1), were all positive, an indication that the average maximum temperature of the period was higher than the reference normal. The largest anomalies were in February (2.92° C) and December with (2.32° C) and November with (2.26° C), compared to the summer months of August (1.26° C), July (1.25° C) and June with (1.13° C). The average total anomaly for the analyzed period was 1.8° C, indicating an upward trend. The graphical representation of the minimum and maximum multiannual average monthly temperatures are presented in (Figure 5 c-d), and the analysis of trends is shown in (Table 1). Both the minimum and maximum monthly values show a positive trend.

Table 1 Statistical analysis of temperature data between 1986-2020 with MAKESENS software.

Period	Mean (°C)	Min (°C)	Max (°C)	S.D. (δ)	C.V. (%)	M.K. (Z)	Signific. (α)	S.S. (Q)	Skewness (S)	Kurtosis (K)
January	-2.50	-7.3	2.1	2.147	-85.880	0.128		0.008	-0.164	0.037
February	-0.52	-7	4.5	2.918	-561.154	1.449		0.068	-0.683	-0.187
March	4.55	-0.5	7.8	2.161	47.495	1.294		0.054	-0.545	-0.171
April	10.66	5.7	14.8	1.678	3.609	1.280		0.042	-0.190	1.487
May	15.64	12.4	19.3	1.454	9.297	0.968		0.020	0.361	0.300
June	19.02	17.2	21.6	1.133	5.957	3.627	***	0.069	0.357	-0.398
July	20.70	18.5	24.8	1.255	6.063	1.309		0.025	0.779	2.102
August	20.21	17.3	22.6	1.261	6.239	3.370	***	0.079	-0.063	-0.423
September	15.14	12.3	18.6	1.619	10.694	2.148	*	0.065	0.331	-0.723
October	9.38	6.4	11.6	1.214	12.942	1.849	+	0.033	-0.538	0.136
November	3.87	-1	9.2	2.258	58.346	1.907	+	0.067	-0.286	0.364
December	-1.11	-7.5	3.4	2.324	-209.369	2.076	*	0.074	-0.719	0.679
Spring (M-A-M)	9.73	-0.5	19.3	1.452	14.125	1.989	*	0.042	-0.468	-0.023
Summer (J-J-A)	19.97	17.2	24.8	0.879	4.402	4.218	***	0.053	0.709	1.020
Autumn (S-O-N)	9.46	-1	18.6	1.066	11.268	3.282	**	0.056	0.023	-0.199
Winter (D-J-F)	-1.38	-7.5	4.5	1.452	-105.217	2.059	*	0.054	-0.172	-0.628
Annual	9.60	-7.5	24.8	0.758	7.904	4.034	***	0.051	0.056	-1.050

Note: SD= Standard Deviation, CV= Coefficient of variation, MK= Mann-Kendal statistics, *Signific= Significance; (+)= 0.1 significance level having 99 % significance interval,* (*)= significance level 0.05 having 95 % significance interval, (**)= 0.01 level of significance, (***)= 0.001 level of significance, blank cell= significance level is greater than 0.1, S.S.= Sen's Slope.

5. Conclusion

To identify the multiannual trends of the monthly, seasonal and annual averages of air temperature, the data were analyzed over a period of 35 years (1986-2020). The Mann-Kendall test shows long-term positive trends, but these are much more evident in the last decade. Sen's slope also indicates the increasing magnitude of the slope, consistent with Mann-Kendall test values. The distribution tests indicate the values of Skewness (S) are quite close to 0 and the value Kurtosis (K) are in the range -1/2 and +1/2, which means that the distribution is not far from symmetrical. A brief description of the results of the study:

i) the multiannual average value had an upward trend from 9.3 ° C to 9.6 ° C;

ii) the most important increase in the average seasonal air temperature was in the summer season;

iii) the averages of multiannual monthly temperatures showed increasing trends for all twelve months of the year;

iv) the annual average of minimum and maximum temperatures shows positive and significant trend;

Of the 35 years analyzed, 23 years (62.8%) showed positive trends in the evolution of air temperature, compared to 12 years (37.2%), which showed annual averages below the value of the reference period. Short-term observations are completed by emergency measures, but long-term analysis of climate elements is vital for assessing the impact on society, the economy and the natural ecosystem, which will increase in the future. The results of the statistical analysis show an increase in air temperature, constant in recent decades confirming the general trends in global warming.

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