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ASSESSING AVERAGE ANNUAL AIR TEMPERATURE TRENDS USING THE MANN–KENDALL TEST IN KOSOVO

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Temperatures were confirmed to rise in Kosovo in the last decades.

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Assessing average annual air temperature trends using the Mann–Kendall test in Kosovo

ABSTRACT: The annual trends of surface mean monthly air temperature and monthly extreme temperatures were analyzed from ten meteorological stations in Kosovo. The data refer to observation periods between 1949 and 1999 for four stations, and observation periods between 1965 and 1999 for the remaining six stations. Trends were analyzed for nine time series. Positive trends were found in six series, and negative trends were found in three series. After an assessment of these trends using the Mann–Kendall test, positive trends were confirmed in four series, a negative trend was confirmed in one series, and in one series there was no trend, whereas trends were characterized as slightly positive in two time series and slightly negative in one series.

KEY WORDS: air temperature trends, climate change, Mann–Kendall test, Kosovo

Ocena trendov povprečnih letnih temperatur zraka na Kosovu z uporabo Mann-Kendallovega testa

POVZETEK: V raziskavi so bili analizirani letni trendi povprečnih in ekstremnih mesečnih temperatur zraka, izmerjenih na desetih meteoroloških postajah na Kosovu. Podatki se pri štirih postajah nanašajo na opazovalno obdobje 1949–1999, pri preostalih šestih postajah pa na opazovalno obdobje 1965–1999. Trendi so bili analizirani za devet časovnih nizov. Pozitivni trendi so bili ugotovljeni v šestih nizih, negativni pa v treh. Po oceni teh trendov z uporabo Mann-Kendallovega testa so bili pozitivni trendi potrjeni v štirih nizih, negativni trend je bil potrjen v enem nizu, v enem nizu trenda ni bilo, rahlo pozitivni trendi so bili potrjeni v dveh časovnih nizih in rahlo negativni v enem nizu.

KLJUČNE BESEDE: trendi temperatur zraka, podnebne spremembe, Mann-Kendallov test, Kosovo

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1 Introduction

According to the Intergovernmental Panel on Climate Change (IPCC 2007) report, the average global surface air temperature of the world has increased by 0.7 °C in the last hundred years. Klein Tank et al. (2002) showed that trends in average temperature increased in the period between 1946 and 1999 in Europe. This increase in global and regional temperature varies seasonally and regionally. In Europe the trends are higher in central and north-eastern areas and in mountainous regions, whereas lower trends are found in the Mediterranean region and temperatures are increasing higher in winter than summer (all during the period from 1977 to 2000; Alcamo et al. 2007).

Historically, the climate of Kosovo has generally been analyzed as part of the climate of Serbia and Yugoslavia. Using extreme temperatures at fifteen meteorological stations in Serbia, Unkašević and Tošić (2013) suggested that the climate in the region warmed up between 1949 and 2009. Analyzing data between 1949 and 2007, Unkašević and Tošić (2009a) found that a slow decrease in summer temperatures until 1975 was followed by a temperature increase lasting until 2007. In addition to these papers, other recent works addressing the climate in Serbia with and without Kosovo have been published (Jovanović et al. 2002; Gburčik et al. 2006; Đorđević 2008; Unkašević and Tošić 2009b; Gavrilov et al. 2010; 2013; Pavlović Berdon 2012; Hrnjak et al. 2014; Tošić et al. 2014; Gavrilov et al. 2015; 2016). In addition, the weather and climate of Kosovo were investigated in the work of Sokolović et al. (1984).

This study focuses on average annual air temperature trends in Kosovo from 1949 to 1999 and from 1965 to 1999. The first period contains nearly two thirty-year-climate cycles, and the second contains more than one thirty-year-climate cycle. Therefore the results are proper indicators for recent climate change.

2 Area and data

2.1 Study area

Kosovo is located in the southwestern part of the Balkan Peninsula and covers an area of 10,887 km^2 (Figure 1). Its geomorphological characteristics and geographical location divide it into two regions; Kosovo proper in the east is a plateau with a relatively consistent elevation, and Metohija in the west is a hilly area bordered by high mountains. The climate of Kosovo is moderate continental with cold winters and warm summers, with a great range of extreme temperatures and a non-uniform distribution of rainfall. The average annual air temperature is 10.8 °C, and the annual amount of precipitation between 1949 and 1999 was 669 mm (Internet 1).

2.2 Data

This work contains an analysis of surface air temperature trends obtained from ten meteorological stations. The locations of the stations are presented in Figure 1, and their main parameters are given in Table 1

Table 1: List of meteorological stations and their geographical coordinates and elevations.

Number	Meteorological station	Elevation (m)	Latitude (°N)	Longitude (°E)
Stations operated from 1949 to 1999				
1	Kosovska Mitrovica	510	42° 53'	20° 52'
2	Peć	498	42° 40'	20° 18'
3	Prizren	402	42° 13'	20° 44'
4	Priština	573	42° 39'	21° 09'
Stations operated from 1965 to 1999				
5	Istok	465	42° 47'	20° 30'
6	Skivijane	415	42° 28'	20° 21'
7	Suva Reka	420	42° 21'	20° 49'
8	Gnjilane	520	42° 28'	21° 29'
9	Uroševac	580	42° 23'	21° 10'
10	Dragaš	1060	42° 04'	20° 39'

in accordance with the Republic Hydrometeorological Service of Serbia. Meteorological stations were divided into two groups, depending on the periods in which they were first established and operational. The first group consists of four stations that operated from 1949 to 1999, and the second group consists of the remaining six stations, which operated from 1965 to 1999. Nine of the stations have a relatively uniform elevation, varying between 402 m and 580 m, whereas the Dragaš station has an elevation of 1,060 m (in this paper it is referred to as a mountain station).

In order to obtain trends, we used three data sets: monthly mean temperatures, monthly maximum temperatures, and monthly minimum temperatures for all stations. From the monthly temperatures, the average annual mean temperatures, average annual maximum temperatures, and average annual minimum temperatures were calculated. Finally, from these three types of average annual temperatures, new data sets were derived, marked as: T, T_x, and T_n, respectively, for trend calculations for Kosovo (K) over two periods: 1949–1999 (P1) from four stations (Kosovska Mitrovica, Peć, Prizren, and Priština) and 1965–1999 (P2)

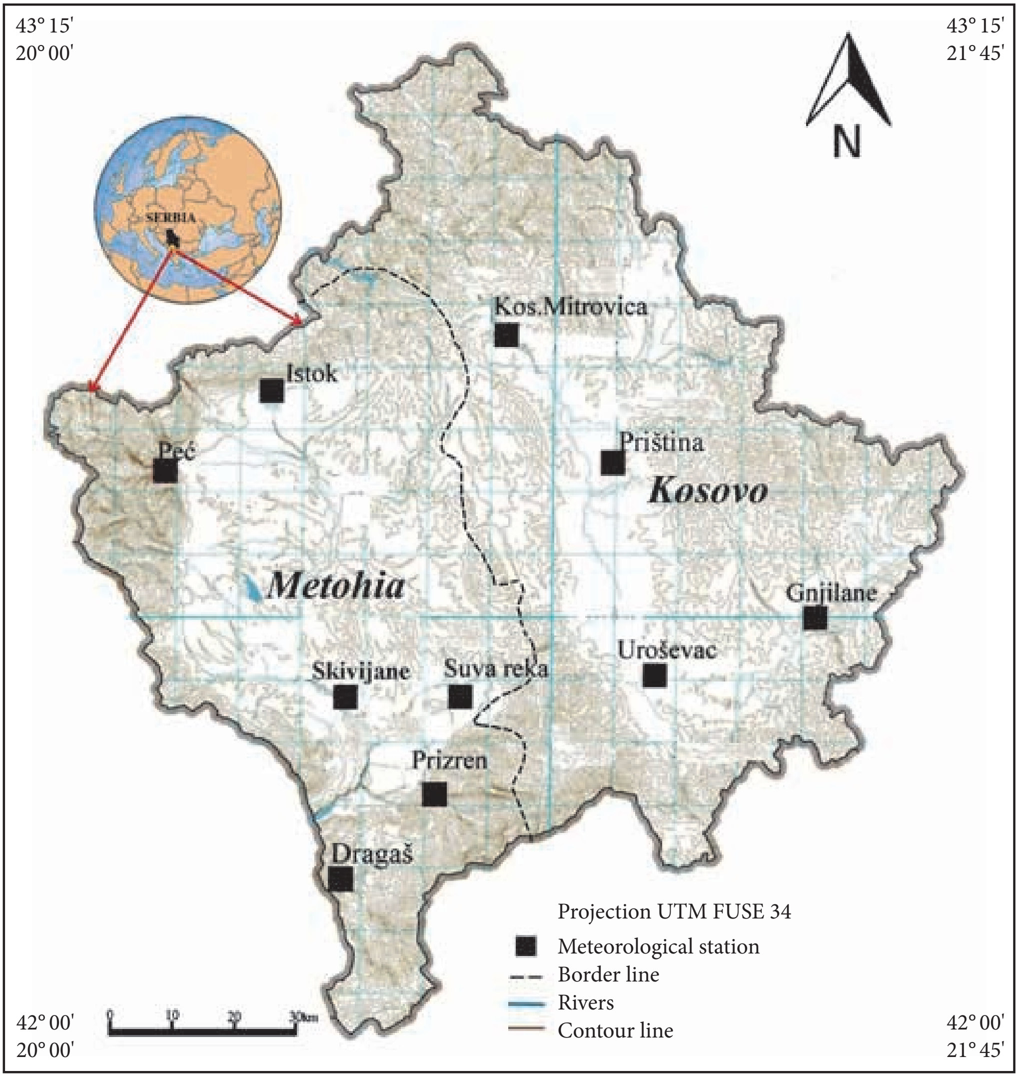


Figure 1: Kosovo.

from five stations (Istok, Skivijane, Suva Reka, Gnjilane, and Uroševac); whereas Dragaš (D) was treated as a special data set because it is a mountain station, with data available for the period from 1965 to 1999 (P2). Each of these data sets is marked with an acronym consisting of the abbreviation for the territory/station, period, and type of temperature. In total, all nine data sets (time series) were used for trend calculation (Table 2).

Table 2: List of nine time series to calculate air temperatures trends.

Territory/station	1949–1999 (P1)	1965–1999 (P2)
	K-P1-T	K-P2-T
Kosovo (K)	K-P1-T_x	K-P2-T_x
	K-P1-T_n	K-P2-T_n
	–	D-P2-T
Dragaš (D)	–	D-P2-T_x
	–	D-P2-T_n

Before the previous calculation, the homogeneity of the temperature data was examined according to the Alexandersson (1986) test. The test showed that the time series are not non-homogeneous for a significance level of 5%.

3 Methods

Temperature trends were analyzed for nine time series using two statistical approaches: calculation of the linear temperature trend equation and application of the Mann–Kendall test.

The first approach was to calculate the tendency (trend) equation of temperature using linear interpolation of the average annual temperatures (Wibig and Glowicki 2002). This method was used to determine the sign of the temperature trends and the trend magnitude (Gavrilov et al. 2015; 2016) as the difference in temperatures between the beginning and end of both periods P1 and P2.

The second statistical approach used the Mann–Kendall test (Kendall 1975; Gilbert 1987) to indicate statistically significant trends. The Mann–Kendall test is widely used in analysis of climatologic time series; for example, temperature and precipitation (Karmeshu 2012), extreme temperatures (Wibig and Glowicki 2002), hail (e.g., Gavrilov et al. 2010, 2013), aridity (Hrnjak et al. 2014), evapotranspiration (Tabari et al. 2011), and atmospheric deposition (Drapela and Drapelova 2011), and also in hydrological time series (Yue and Wang 2004) and other geophysical time series, such as soil freezing and thawing (Sinha and Cherkauer 2007) because it is simple and robust, and it can cope with missing values and values below the detection limit.

In using the Mann–Kendall test to define statistically significant trends, two hypotheses were tested: the null hypothesis, H_0, that there is no trend in the time series, and the alternative hypothesis, H_a, that there is a trend in the time series for a given significance level. Probability p in percent (Karmeshu 2012; Gavrilov et al. 2016) was calculated to determine the level of confidence in the hypothesis. If the computed value p is lower than the chosen significance level α (e.g., $\alpha = 5\%$), the H_0 (*there is no trend*) should be rejected, and the H_a (*there is a significant trend*) should be accepted; and if p is greater than the significance level α then the H_0 is accepted (or cannot be rejected). For calculating probability p and hypothesis testing, XLSTAT statistical analysis software was employed (Internet 2).

It is considered that accepting the H_a indicates that a trend is statistically significant. On the other hand, acceptance of the H_0 implies that there is no trend (no change), whereas often in practice the trend equation indicates the opposite; that is, that there is a trend. Therefore, to reduce the contradictions in analyzing the temperature trends between two independent statistical approaches – the trend equation and the Mann–Kendall test – the modified interpretation of the Mann–Kendall test will be offered. Moreover, this interpretation makes it possible to obtain more diverse results.

It is quite clear that, with decreasing probability p, statistical confidence in the H_0 decreases and confidence in the H_a increases, and vice versa. Because probability p takes values between 0% and 100%, for the purposes of this study a modified interpretation of the Mann–Kendall test was introduced and four levels of confidence were defined (Gavrilov et al. 2015; 2016). When the computed probability p is: (1) less or equal to 5%, the trend is significantly positive/negative; (2) greater than 5% and less than or equal to 30%, the trend is moderately positive/negative; (3) greater than 30% and less than or equal to 50%, the trend is slightly positive/negative; and (4) greater than 50%, there is no trend. As can be seen, in cases (1) and (4) both interpretations of the Mann–Kendall test have the same meaning; namely, that there is a significant trend and that there is no trend. Differences occur in cases (2) and (3), where the Mann–Kendall test claims there is no trend, and the modified Mann–Kendall test allows a trend with reduced levels of confidence.

4 Results and discussion

4.1 The values of trends

By applying both statistical approaches to each of the nine time series in Table 2, nine cases are obtained (Table 3).

Table 3: The trend equation *y*, the trend magnitude Δ*y*, and probability *p* of the confidences for all time series.

Time series	Trend equation	Δ*y* (°C)	*p* (%)
K-P1-T	$y = -0.006\,x + 10.97$	0.3	25
K-P1-T_x	$y = 0.013\,x + 23.50$	–0.7	17
K-P1-T_n	$y = 0.012\,x - 1.40$	–0.6	4.5
K-P2-T	$y = 0.021\,x + 10.31$	–0.7	1
K-P2-T_x	$y = 0.024\,x + 23.42$	–0.8	2
K-P2-T_n	$y = 0.011\,x - 2.17$	–0.4	24
D-P2-T	$y = -0.003\,x + 8.31$	0.1	89
D-P2-T_x	$y = 0.070\,x + 20.41$	–2.5	1
D-P2-T_n	$y = -0.047\,x - 1.76$	1.7	1

In Table 3 the first column is the time series; the second column is the linear trend equation, where *y* is the average annual value of the temperature in °C and *x* is the time in years; Δ*y* is the trend magnitude in °C; and *p* is the probability in percent, $\alpha = 5\%$ is the significance level (it is the same in all cases).

4.2 Evaluation of trends

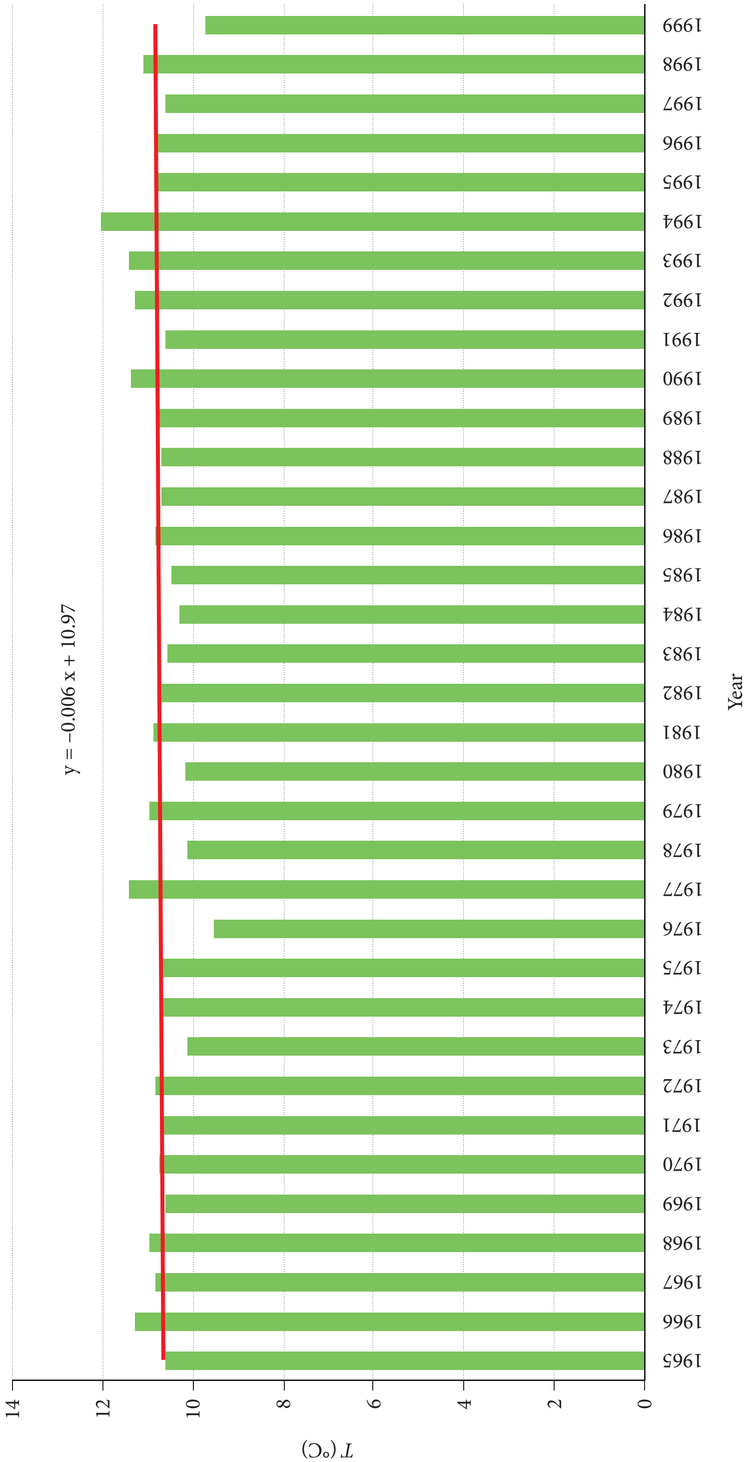
In strictly formal terms, as evidenced by the trend equations in Table 3, in all cases some trends can be observed. However, not all trends have the same sign, magnitude, and probability. To obtain the final evaluation of temperature trends, values from Table 3, Figures 2–4, and the results of hypothesis testing were used.

Figure 2 and the trend equations for the time series K-P1-T, K-P1-T_x, and K-P1-T_n show that the trends are negative once and positive twice, respectively. Mann–Kendall test will prove whether these statements are true. Because the probabilities *p* are greater than the significance level, $\alpha = 5\%$, the H_0 cannot be rejected in the first two cases. The risk of rejecting the H_0 while it is true are 25% and 17%, respectively. Because the *p* in K-P1-T_n is lower than the significance level, the H_0 should be rejected and the H_a should be accepted. The statement that there is a trend is correct with a probability greater than 95%. In accordance with the modified Mann–Kendall test, these three trends are characterized as moderately negative, moderately positive, and significantly positive, respectively.

Figure 3 and the trend equations for the time series K-P2-T, K-P2-T_x, and K-P2-T_n show that the trends are positive in all cases. Mann–Kendall test will prove whether these statements are true. Because the probabilities *p* in K-P2-T and K-P2-T_x are lower than the significance level, $\alpha = 5\%$, the H_0 should be rejected and the H_a should be accepted in both cases. The statement that there are trends is correct with a probability greater than 98%. Because the *p* in K-P2-T_n is greater than the significance level, the H_0 cannot be rejected. The risk of rejecting the H_0 while it is true is 24%. In accordance with the modified Mann–Kendall test, these cases are characterized as significantly positive twice and moderately positive once, respectively.

Figure 4 and the trend equations for the time series D-P2-T, D-P2-T_x, and D-P2-T_n show that the trends are negative, positive, and negative, respectively. Mann–Kendall test will prove whether these statements are true. Because probability *p* in D-P2-T is greater than the significance level, $\alpha = 5\%$, the H_0 cannot be rejected.

Figure 2a


y = −0.006 x + 10.97
T (°C)
Year
0
2
4
6
8
10
12
14
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
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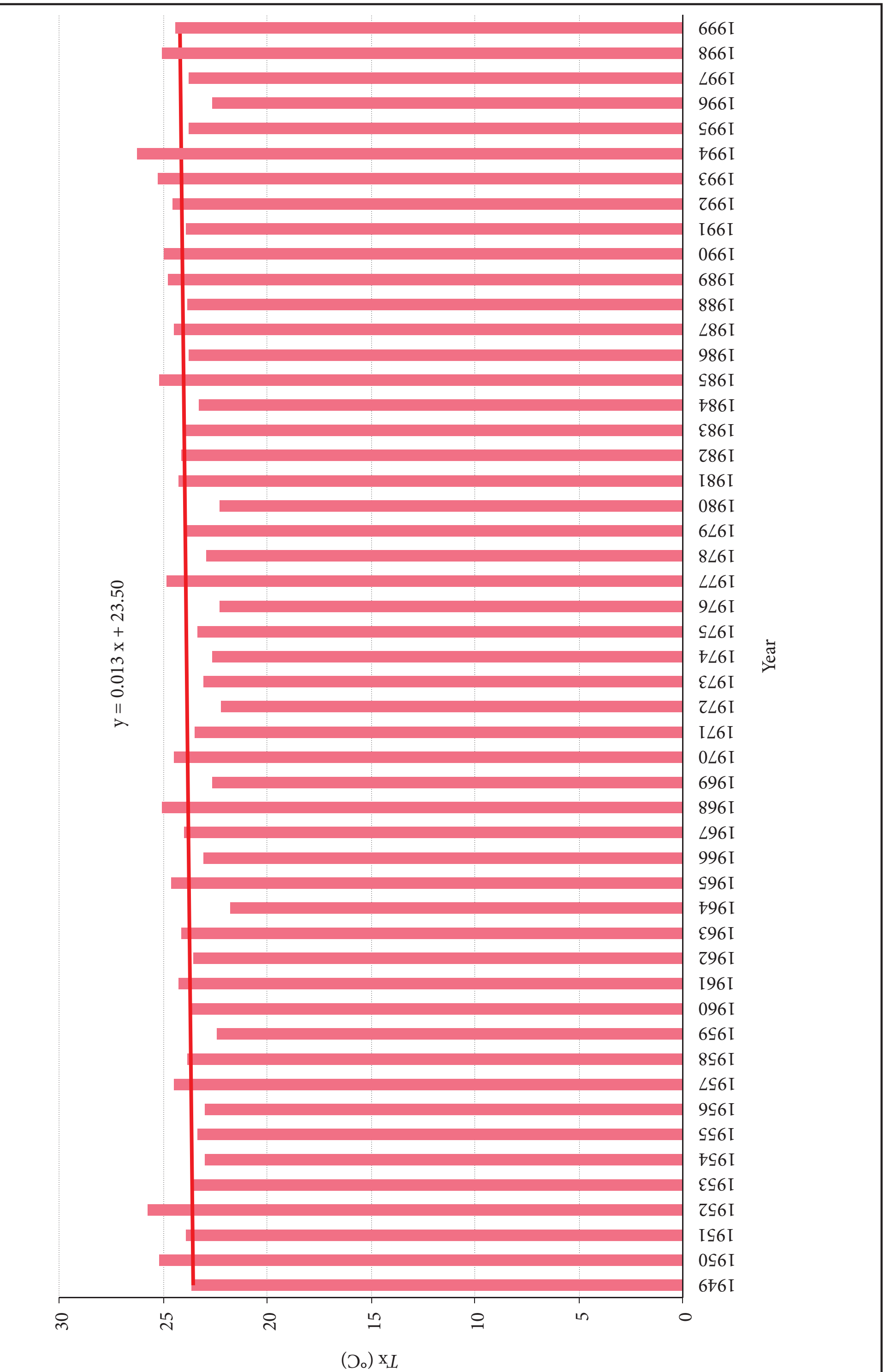

y = 0.013 x + 23.50
Tx (°C)
Year
0
5
10
15
20
25
30
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
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1997
1998
1999

Figure 2b

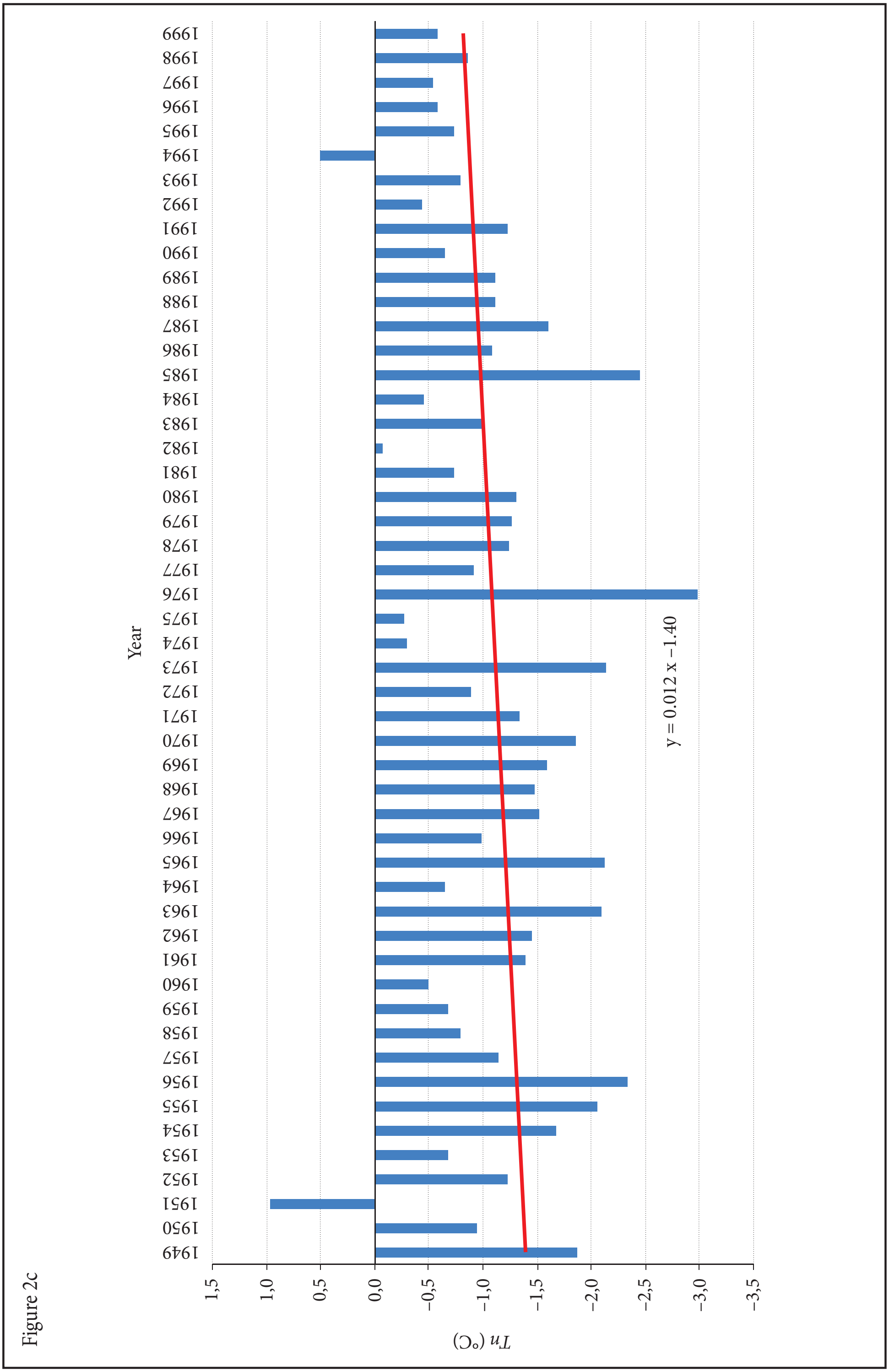
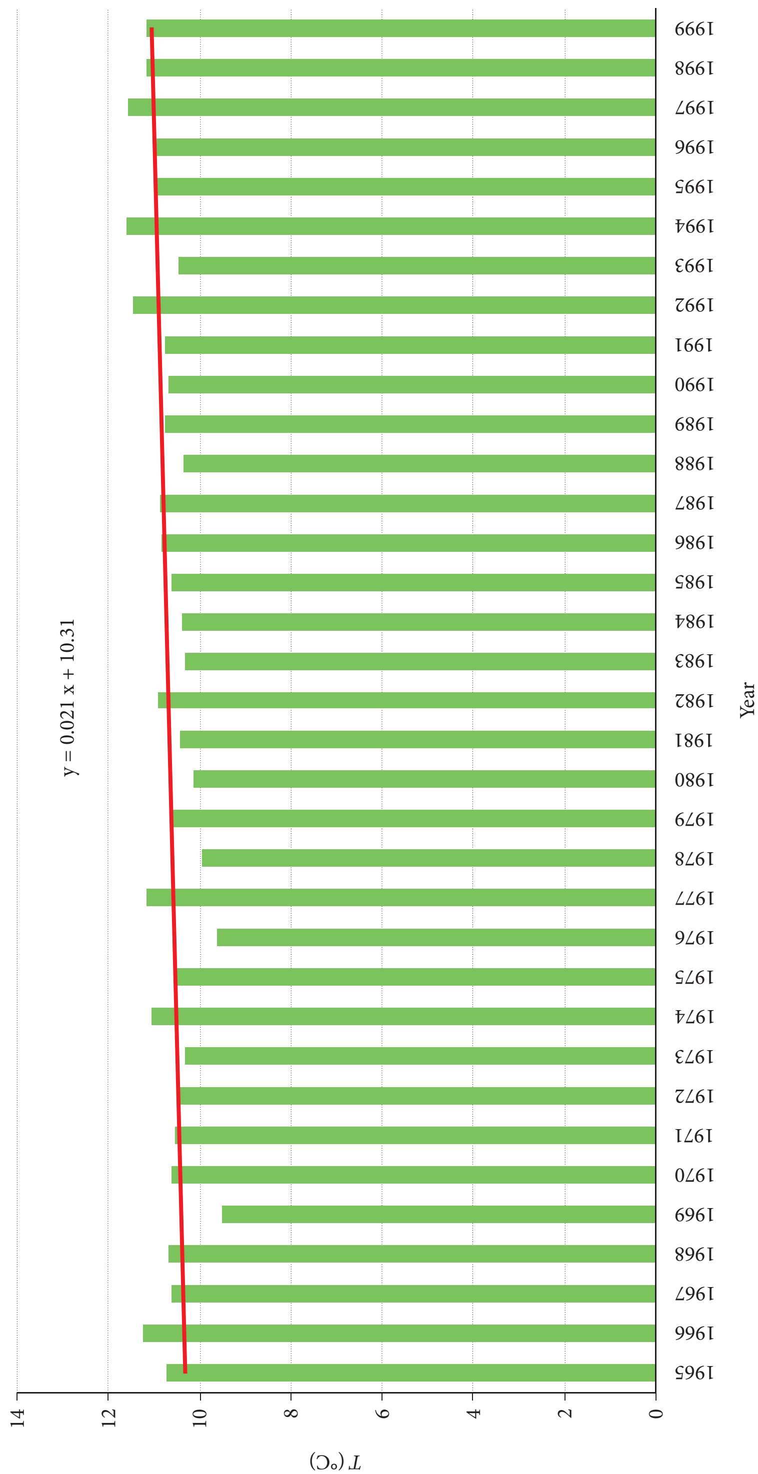


Figure 2: Distribution by year of the three types of temperatures: T, T_x, and T_n; the trend lines and the trend equations of temperatures in Kosovo for period P1 on panels a, b, and c, respectively.

Figure 3a


y = 0.021 x + 10.31
T (°C)
Year
0
2
4
6
8
10
12
14
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
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1990
1991
1992
1993
1994
1995
1996
1997
1998
1999

Figure 3b


y = 0.024 x + 23.42
Tx (°C)
Year
0
5
10
15
20
25
30
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
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1999

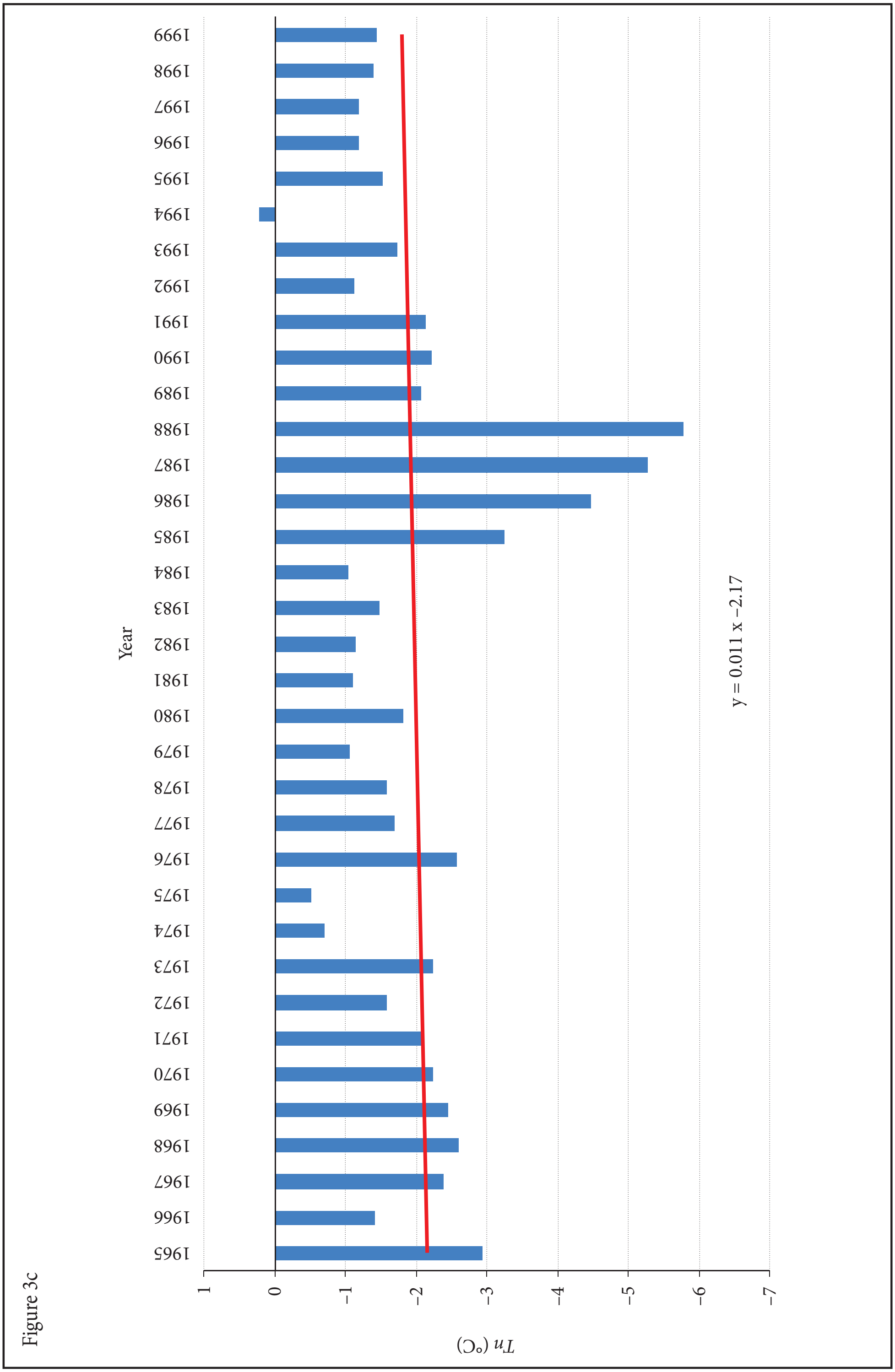
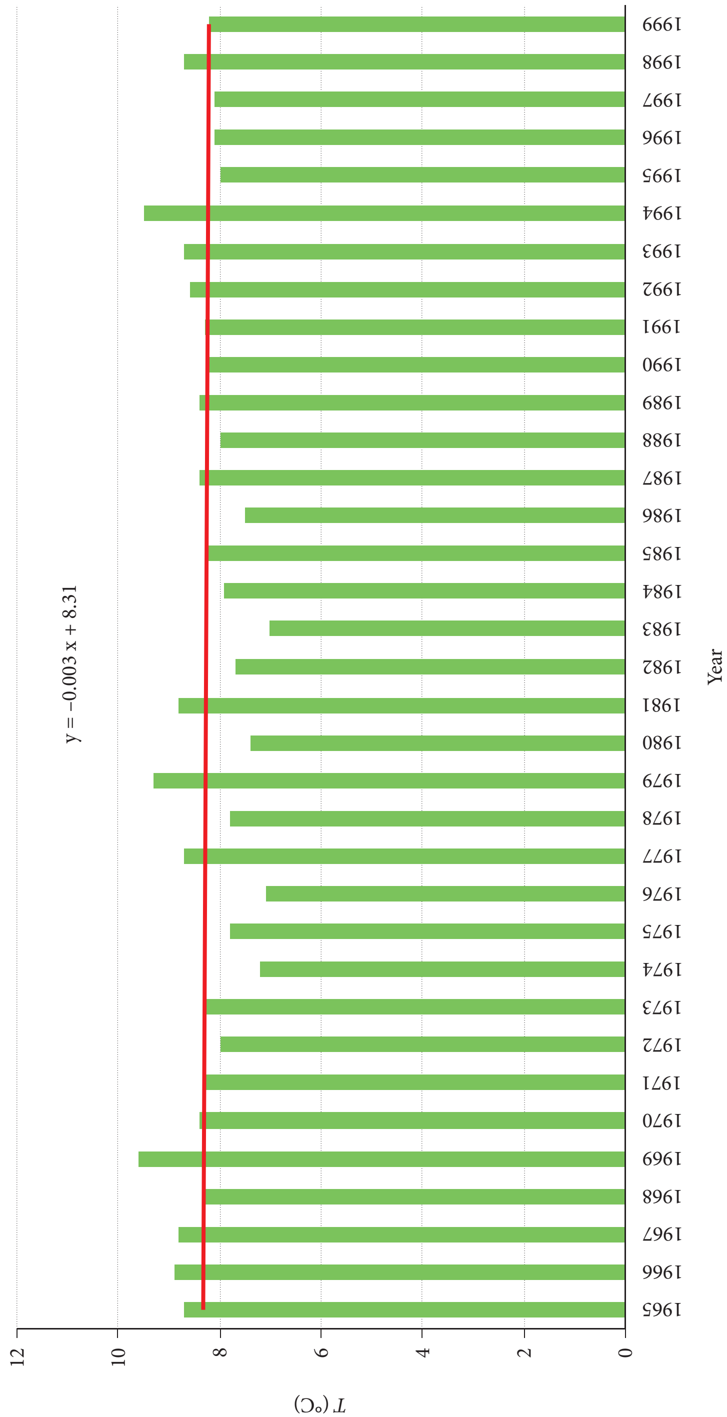


Figure 3: As in Figure 2, but for period P2.

Figure 4a


y = −0.003 x + 8.31
T (°C)
0
2
4
6
8
10
12
Year
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
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1985
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1988
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1990
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1992
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1994
1995
1996
1997
1998
1999

Figure 4b


y = 0.070 x + 20.41
Year
Tx (°C)
0
5
10
15
20
25
30
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
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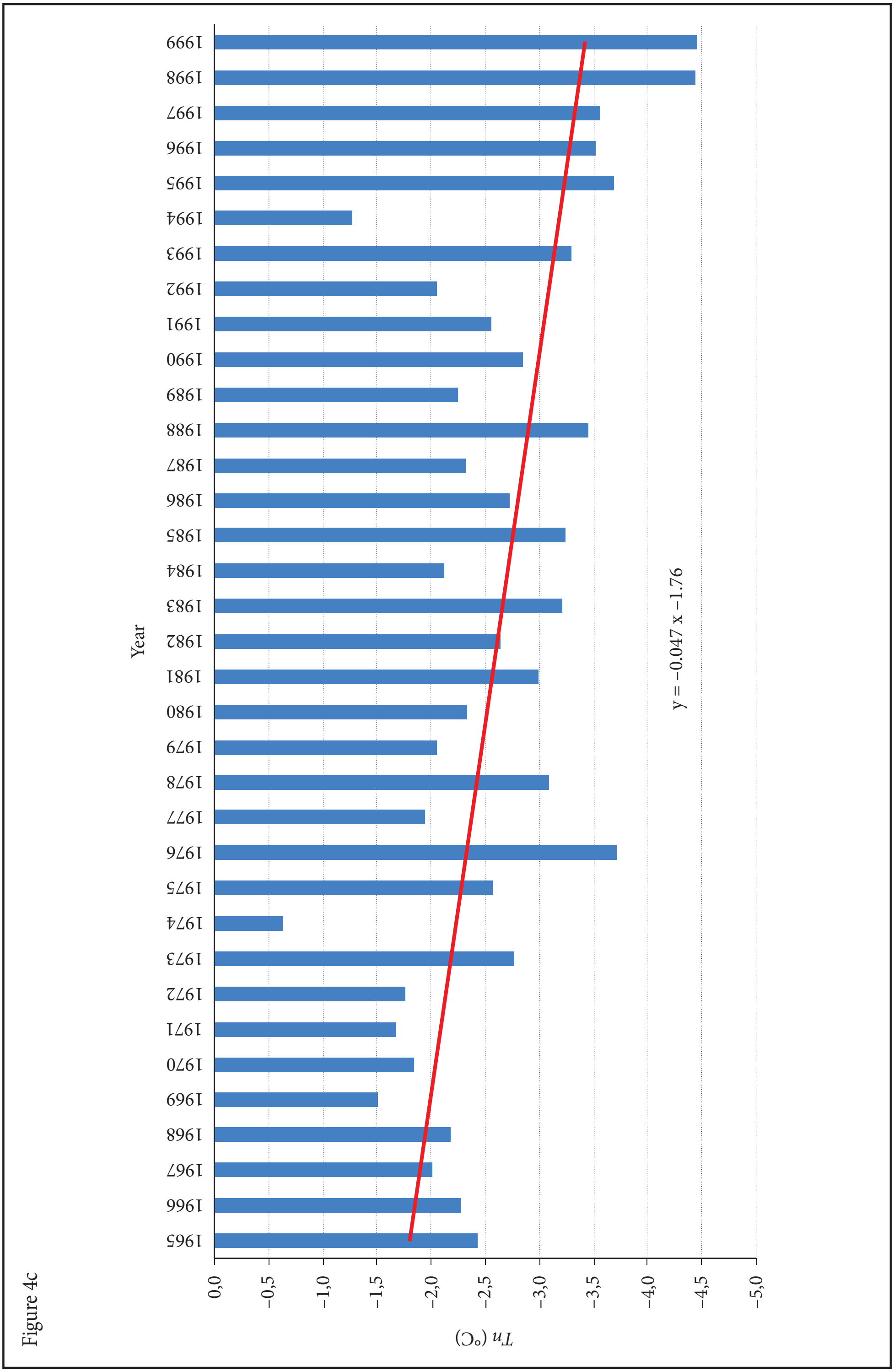

Figure 4: As in Figure 2, but at the Dragaš station.

The risk of rejecting the H_0 while it is true is 89%. Because the probabilities p in D-P2-T_x and D-P2-T_n are lower than the significance level, the H_0 should be rejected and the H_a should be accepted in both cases. The statement that there are trends is correct with a probability greater than 99%. Now, the trends are characterized as no trend, significantly positive, and significantly negative, respectively. It should be noted that in the case D-P2-T the Δy is equal to the standard error of the temperature measurement, and so it is also considered no trend.

5 Conclusions

The main results of the analysis of temperature trends in Kosovo are shown in Table 4.

Table 4: The main results of the analysis of trends.

Time series	Trend equation	Modified Mann–Kendall test
K-P1-T	*Negative trend*	*Negative moderate trend*
K-P1-T_x	*Positive trend*	*Positive moderate trend*
K-P1-T_n	*Positive trend*	*Positive significant trend*
K-P2-T	*Positive trend*	*Positive significant trend*
K-P2-T_x	*Positive trend*	*Positive significant trend*
K-P2-T_n	*Positive trend*	*Positive moderate trend*
D-P2-T	*Negative trend*	*No trend*
D-P2-T_x	*Positive trend*	*Positive significant trend*
DP-2-T_n	*Negative trend*	*Negative significant trend*

Based on the trend equations, positive trends were found in six and negative trends were found in three time series. After applying the Mann–Kendall test, significantly positive trends were confirmed in four time series, a moderately positive trend was found in two time series, and a significantly negative trend, moderately negative trend, and no trend were found in a single case each.

From the results presented above, it is very difficult to derive an overall general rule, but some conclusions can be drawn. First, positive temperature trends dominate. All of them could be explained by the effects of global warming on Kosovo. This impact is most evident in the case of representative time series K-P2-T, which covers the 1980s and 1990s, when the effect of global warming was first detected in the region (Gavrilov et al. 2016). On the other hand, the representative case K-P1-T was also influenced by global warming, but no positive trend was noted. This can be explained by impacts from the 1960s and 1970s, when there were no signs of global warming (Hardy 2006).

In the case of the Dragaš mountain station, the results were very diverse. There, all three trends were found: positive, negative, and no trend. This case, as well as a detailed explanation of other cases, requires additional research.

In spite of the limited meteorological data available, the results presented provide insight into the climate dynamics of the region.

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