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Trends and changes of mean, maximum, minimum temperature and precipitation series in Northern Cyprus

Kuzey Kıbrıs'ın ortalama, maksimum, minimum sıcaklık ve yağış dizilerindeki eğilimler ve değişiklikler

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Abstract

Seasonal temperature and precipitation series of Girne and Lefkoşa stations in Northern Cyprus were investigated with respect to the long-term trends and changes. Results of the study have led to the following main conclusions: (1) Statistically significant increasing (warming) trends were found in mean temperatures of Girne, while mean temperatures of Lefkoşa were statistically random against to any trend in all seasons; (2) Statistically significant and the strongest warming trend showed up mainly in minimum temperatures at both stations in all seasons; (3) Increasing trends in maximum temperatures were not as strong as in mean temperatures at Girne and in minimum temperatures of both stations; (4) Warmer than long-term average temperature conditions in the series was evident especially after the year 1990; (5) However, precipitation series did not show any significant trend, being characterized mainly by wetter or drier than long-term average conditions.

Key words: Northern Cyprus, temperature and precipitation, trend, change points and serial correlation.

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Introduction

Climate change, whether its global or regional scale, is one of the most significant and far-reaching challenges that the human societies living in the Earth's surface have faced in the 21st century as it was in the 20th century. The evidence of human-induced climate change has been getting stronger on different spatial scales. Climate change has been damaging ecological, social and economical systems. More recently, the International Climate Change Taskforce (2005) recommended, based on the extensive review of the relevant scientific literature, such as Intergovernmental Panel on Climate Change (IPCC, 2001a, 2001b) and other related individual and institutional scientific publications and papers, "a long-term objective of preventing average global surface temperature from rising by more than 2°C above its pre-industrial level (taken as the level 1750, when carbon dioxide (CO_2) concentrations first began to rise appreciably as a results of human activities)." Beyond the 2°C level, the risks to human societies and ecosystems grow significantly. For instance, it is likely that global average surface temperature increases larger than this will entail substantial agricultural losses, greatly increased numbers of people at risk of water shortages, and widespread adverse health impacts (Parry et al., 2001).

The Mediterranean basin takes part mainly in the subtropical zone between the humid mid-latitudes and the dry and hot northern Africa (tropical) zone. It is likely that the risks facing the Mediterranean countries are in two directions: first includes changes in the hydrological cycle and water resources, aridity and desertification conditions, and second consists of increased extreme events such as heat waves, heavy rainfall and floods. Thus, all types of variability, their nature and magnitude and impacts of both natural and human-induced climate changes in the Mediterranean region must be deeply investigated. Some previous studies about observed temperature change and variability over the Mediterranean basin and its surroundings could be listed as follows: Estaban-Parra and Rodrigo (1995); Türkeş et al. (1995, 1996); Kadıoğlu (1997); Kutiel and Maheras (1998); Ben-Gai et al. (1999); Price et al. (1999); Brunetti et al. (2000); Türkeş et al (2002); Türkeş and Sümer (2004). More warmer summers, new maximum temperature anomalies and records, and drying are the main indicators of the observed climate change in the Mediterranean basin. A warming trend is detected from the last quarter of 18th century to present for the Mediterranean basin (Kutiel and Maheras, 1998). Mean and minimum temperatures increased and maximum temperatures did not represent any significant trend in Northern Spanish and minimum temperatures have the biggest influence over the eastern Mediterranean (Estaban-Parra and Rodrigo, 1995).

Mean temperatures have a general increasing trends in for annual, winter and spring and diurnal temperature ranges significantly decreased at most of the urbanized and rapidly urbanizing stations throughout the seasons except partly in winter over Turkey (Türkeş et al., 2002). Price et al. (1999) found, for two stations of Cyprus, an increasing trend with a rate of about 1°C/100 years in annual mean temperatures. They showed that minimum temperatures generally increased at a larger rate than in maximum temperatures, resulting in a decrease in diurnal temperature range (DTR).

Decreasing in precipitation totals over the Mediterranean region is emphasized on a large scale. In addition to trends, precipitation variations over the Mediterranean region are characterized mainly by runs of dry and wet (rainy) periods: generally wet periods are weak, short and infrequent, while dry periods are strong, long and frequent. Some examples for the studies about precipitation changes and trends of the Mediterranean region, especially in the central and eastern Mediterranean are as follows: Kutiel et al. (1996); Türkeş (1996, 1998, 2003); Brunetti et al. (2000); Ramos (2001); Xoplaki (2002); Norrant and Douguedroit (2006). In the Mediterranean basin, annual rainfall did not show a clear tendency, but during the last decade inter-annual variability decreased (Ramos 2001). The number of extremely wet years or seasons was double the number of extremely dry years or seasons, while wet sequences are fewer and shorter than dry sequences at four stations of the eastern Mediterranean (Kutiel et.al., 1996). Precipitation trends were appear to be significantly diminishing, primarily during winter months, March in the Atlantic region, October in the Mediterranean part of Spain, December in the Lions and Genoa Gulfs, January, winter and annually in Greece, winter and annually in Italy and winter in the Near East, and increasing in April in the two gulfs in the Mediterranean (Norrant and Douguedroit, 2006). The Italian climate became warmer and drier especially at the south since about 1930 and inter-annual variability did not present significant maxima, but only minima that cannot be related to start of a trend in precipitation (Brunetti et al., 2000). Long-term variations in precipitation series were generally characterized by successive periods of wetter and drier than normal precipitation conditions. For annual and winter precipitation anomaly series, wet conditions generally occurred during the 1940s, 1960s, late 1970s, early 1980s and mid-late 1990s, whereas dry conditions generally dominated over the early-mid 1930s, early-mid 1970s, mid-late 1980s, early 1990s, and 1999/2000 over most of Turkey (Türkeş, 1998, 2003).

By taking into consideration all of these studies, it can be summarized that the Mediterranean climate is characterized mainly by dry and wet periods linked to different circulation regimes throughout the year. Circulation dynamics include a high variability of precipitation on various time scales. There have been a general warming trend in many countries, and significant warming trends have been evident particularly in the eastern Mediterranean, such as in Turkey in spring and summer. Particularly winter precipitation in the Mediterranean basin has tended to decrease. However, there is a great gap of information for the climate variability in Northern Cyprus.

Consequently, for describing and explaining the changes and variability in the Mediterranean climate as a whole, we would expect that the present study could contribute the climate science by supporting other regional research results. Thus, the study aims to: (1) give basic information on the contemporary climate of the Northern Cyprus; (2) analyze seasonal temperature and precipitation series recorded at Girne (Kyrenia) and Lefkoşa (Nicosia) with respect to the homogeneity and randomness in the series; (3) apply mainly non-parametric time-series methods to temperature (mean, maximum and minimum) and precipitation series of Girne and Lefkoşa stations to reveal their long-term trends and variations; and (4) explain trend features (i.e., nature and magnitude and change points of observed trends).

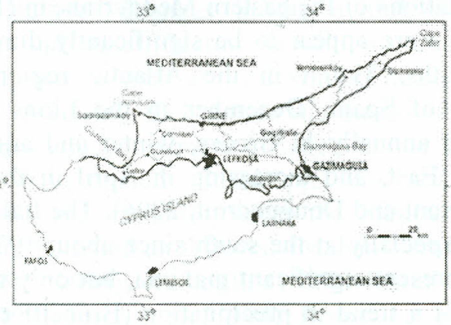


Figure 1. General geographic position of the Cyprus Island and locations of Girne and Lefkoşa stations used in the study along with other major cities of the Island.

Material and Methods

We have used monthly mean (averages of daily means), monthly mean maximum and minimum (averages of daily maximum and minimum) temperatures and monthly precipitation totals recorded at Girne and Lefkoşa stations of Northern Cyprus Turkish State Meteorological Administration (Figure 1).

Lefkoşa station is located at highly urbanized part of the city, while Girne station, which is smaller than Lefkoşa in terms of population and area, is located on Mediterranean cost of Northern Cyprus. Even tough Girne is under the influence of the land and sea breezes (meltem in Turkish), it is also very rapidly urbanizing city. We have arranged these series as climatological seasons: winter consists of December, January and February; March, April and May as spring; June, July and August as summer; September, October and November as autumn. Climatic data of two stations comprise these periods: 1967-2003 for mean temperature series and 1975-2003 for precipitation totals. Maximum and minimum temperature series include the period of 1975-2003 for Girne and 1976-2003 for Lefkoşa.

Seasonal precipitation totals were normalized in order to eliminate likely effects of high year-to-year variability in spring and summer seasons and in particular very low rainfall amounts in summer. A normalized precipitation anomaly (A_{sts}) for a long series of a given station is calculated with

$$A_{sts} = (P_{sts} - \overline{P}_s)/\sigma_s \quad (1)$$

where, P_{sts} is total precipitation amount (mm) for a station *st* during a season *s*; $\overline{P}_s$ and σ_s are long-term average and standard deviation of seasonal precipitation series for that station, respectively.

Thornthwaite's climate classification and water budget of Northern Cyprus were calculated by taking into consideration of the approach used in the WATBUG program, which was developed by Willmott (1977). Some of the outputs that the WATBUG produces are as follows: unadjusted potential evapotranspiration (*UPE*) in mm; adjusted *PE* (*APE*) in mm; soil moisture storage (*ST*) in mm; actual evapotranspiration (*AE*) in mm; soil moisture deficit (*DEF*) and soil moisture surplus (*SURP*) in mm. The WATBUG calculates monthly (or daily) *PE*, according to the Thornthwaite (1948) methodology.
Thornthwaite's Moisture Index (1948) is calculated as follows:

$$L_m = (100S - 60D)/PE \quad (2)$$

where, S is annual water surplus and D, deficit (mm); PE is annual potential evapotranspiration (mm). Negative values of the moisture index are found in dry climates, while positive values are found in moist climates.

For determining whether the time series are homogeneous or not, non-parametric Kruskal-Wallis (K-W) homogeneity test was used (Sneyers, 1990). Homogeneity of a climatic series of observations is influenced mainly by changes of measurement site, instrumentation and observation practice and nearby environmental conditions of that station.

Sample size of sub-periods and significance level of the test were taken as $n_j = 5$ and the 0.05, respectively. We have also verified homogeneity of variances by using the same test. In this case, absolute values of deviations from overall averages of the series were used. Then, we have made a subjective assessment of each statistically significant inhomogeneity by means of additional information available with plotted graphs and our own station history file. Finally, the climatological assessment of each series was made. For the present study, inhomogeneity means non-climatic strong jumps (step-wise changes) in the mean of the series.

Mean and minimum temperatures series have seemed to be inhomogeneous in all seasons in Girne and maximum temperature series in summer are also to be inhomogeneous in Girne. Analysis for homogeneity of variances has shown much better results. Only autumn mean and minimum temperature series were found to be inhomogeneous in Girne.

Lefkoşa station experienced inhomogeneity in minimum temperatures in all seasons and mean temperatures in autumn. According to other test based on variances, mean temperatures of autumn are also inhomogeneous. These inhomogeneities are very much likely due to observed rapid and statistically significant trends in these series rather than non-climatological stepwise changes in the series that are also proved by the Wald-Wolfowitz (W-W) serial correlation test (Table 3). Consequently, we have made use of these series because non-randomness in the series is very likely caused and/or controlled by the rapid and significant trends, which is main subject of the present study.

We have applied a non-parametric W-W serial correlation test to determine the nature and magnitude of the randomness against the serial correlation (Sneyers, 1990). Using the one-sided test, the null hypothesis was rejected for large values of the test statistics u(r). The alternatives to randomness may become an indicator of the presence of a low frequency fluctuation or an abrupt change of trend and a high frequency oscillation in the series (Sneyers, 1992; Türkeş, 1996; Türkeş et al., 2002).

In addition to the homogeneity and randomness tests, we have used two non-parametric tests and one parametric test to detect long-term trends and change points in time series:

(i) We have applied Mann-Kendall (M-K) test to detect any possible non-linear trend in the mean (Sneyers, 1990). When the original observations are replaced by their corresponding ranks y_i for each term y_i, the number n_i of terms y_i preceding it ($i>j$) is calculated with ($y_i>y_j$). Test statistics t is then defined by,

$$t = \sum_{i=1}^{n} nj \qquad (3)$$

and its distribution function, under the null hypothesis, is asymptotically normal with following mean and variance,

$$E(t) = \frac{n(n-1)}{4} \quad (4) \qquad \text{and} \qquad \mathrm{var}(t) = \frac{n(n-1)(2n+5)}{72} \quad (5)$$

Using two-sided test, the null hypothesis of absence of any trend was rejected for large values of | $u(t)$ | with

$$u(t) = [t - E(t)] / \sqrt{\mathrm{var}\, t} \qquad (6)$$

(ii) Second non-parametric test that was also widely used for analyzing non-linear trends in time-series, is Spearman (Sp) rank correlation coefficient r_s, which is calculated based on following equation (Sneyers, 1990),

$$r_s = 1 - \frac{6}{n(n^2-1)} \sum (y_i - i)^2 \qquad (7)$$

and its distribution function, under the null hypothesis, is asymptotically normal with following mean ($E(r_s)$) and variance ($\mathrm{var}(r_s)$):

$$E(r_s) = 0 \quad (8) \qquad \text{and} \qquad \mathrm{var}(r_s) = \frac{1}{n-1} \quad (9)$$

Test statistic is shown with

$$u(r_s) = r_s \sqrt{n-1} \qquad (10)$$

and using two-sided test of the normal distribution again, null hypothesis of absence of any trend was rejected for large values of $| u(r_s) |$.

When the values of $u(t)$ and $u(r_s)$ are significant at a desired level of significance, one can decide whether that is an increasing or decreasing trend depending on $u(t) > 0$ or $u(t) < 0$ and $u(r_s) > 0$ or $u(r_s) < 0$, respectively.

(iii) We have made use of least squares linear regression (LSLR) method to detect linear trends in temperature and precipitation series. In estimating linear regression lines, we have calculated least squares linear regression equations with time as independent variable and climatic series of observations as dependent variables. Statistical significance of each estimated β coefficient was tested by Student's t test with (n-2) degrees of freedom according to Student t distribution. The null hypothesis of absence of any trend was also rejected by using two-tailed test for large values of $| t|$.

We have also used a five-point Gaussian filter, as a low-pass filter, to examine the long-term fluctuations visually in precipitation series.

Results of Analysis

1. Basic climatic characteristics of Cyprus

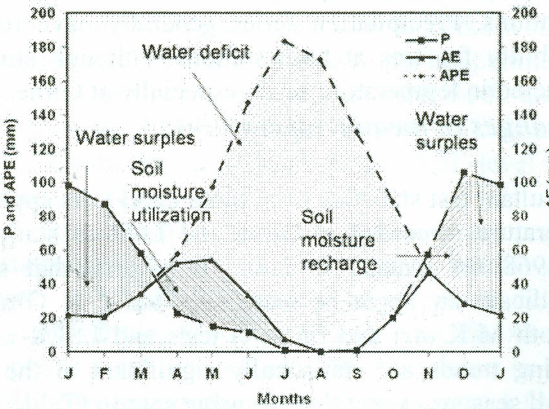
Due to its location over the eastern Mediterranean basin, the Island of Cyprus has been characterized with the Mediterranean macroclimate. The Mediterranean basin lies in an area of great climatic interest. The basin and the surrounding lands are influenced by some of the most relevant atmospheric mechanisms acting upon climate system.

The Mediterranean Sea exists over a transitional zone between the hot deserts of the northern Africa situated in arid zone of the subtropical Azores anticyclone cell and central and northern Europe affected by the mid-latitude cyclones associated with the westerly flows persist almost throughout the year except in summer.

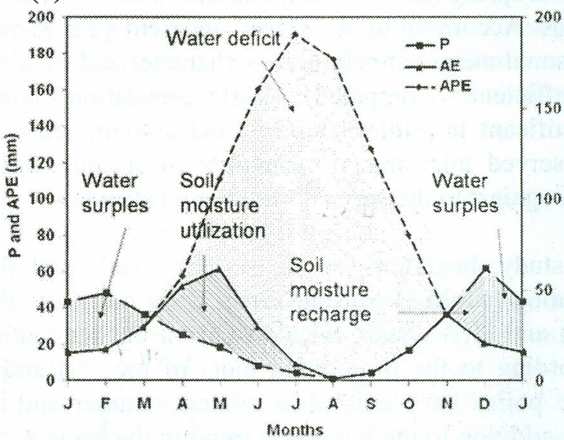
Climate type of Northern Cyprus was determined by Thornthwaite's climate classification (Table 1).

According to Thornthwaite's Moisture Index (I_m), arid climate type is found at Lefkoşa, which is a more continental inland station, while semi-arid climate type is dominant at Girne, which is a coastal station on the Mediterranean coast (Table 1 and Figure 2a, 2b). By referring the Thornthwaite's symbols in Table 1, climatic description of the stations can also be written in detail as follows:

1) Girne is characterized with a **semi-arid climate** being fourth mesothermal, little or no water surplus throughout the year, and with a summer concentration of thermal efficiency equal to a fourth mesothermal climate.



(a)



(b)

Figure 2. Climatic water budget of Girne (a) and Lefkoşa (b) stations according to Thornthwaite's method. (APE: Adjusted potential evapotranspiration, P: Precipitation, AE: Actual evapotranspiration)

2) Lefkoşa is characterized with an **arid climate** being fourth mesothermal, little or no water surplus throughout the year, and with a summer concentration of thermal efficiency equal to a second mesothermal climate.

2. Trends and changes in temperature and precipitation series

Both non-parametric M-K and Sp rank correlation tests and LSLR approach were used in order to evaluate nature and magnitude of the long-term trends in various seasonal temperature and precipitation series. Significant increasing (warming) trends and some types of year-to-year variability or long-period fluctuations in air temperature series were determined for Girne and Lefkoşa stations. Precipitation series generally have revealed similar trend and variability features at both stations, although strong increasing trends were detected in temperature series especially at Girne.

Trends and changes in mean temperatures

Based on the resultant test statistics from three trend tests applied to seasonal mean air temperatures recorded at Girne and Lefkoşa stations during the period 1967 (1968 for winter) to 2003, it is seen that seasonal mean temperatures indicate an apparent increasing trend at Girne (Figure 3). According to both M-K $u(t)$ and Sp $u(r_s)$ tests and LSLR approach, these observed warming trends are statistically significant at the 0.01 level of significance in all seasons except that in spring season (Table 2,3). Observed increasing trend in spring mean air temperatures is not significant in terms of all trend methods. According to W-W test, apparent year-to-year variability observed in seasonal mean temperatures is characterized by a negative serial correlation coefficient. Computed serial correlation coefficients are statistically significant in winter, summer and autumn seasons at the 0.01 level, while observed inter-annual variability in spring mean temperature series is random against to the serial correlation (Table 4).

In the present study, beginning of the secular trends and the periods of significant warming (cooling) were determined by means of the time-series plots of the $u(t)$ and $u'(t)$ values calculated from the sequential analysis of M-K test. According to the time-series plots of the $u(t)$ and $u'(t)$ values, apparent change points have existed in winter, summer and autumn mean temperatures, in addition to the long-term trend in the same series. For mean temperatures of Girne station, beginning point of the significant change on the series was located in the year 1990 for winter and 1993 for summer and autumn seasons (Figure 3 (a, c, d)). The period of significant warming began in the mid-1990s for winter and summer immediately after the change point, and in the late 1990s for autumn (Figure 3 (a, c, d)). On the other hand, there is no any significant change point and warming (cooling) period in the mean air temperature series of Lefkoşa station (Figure 4).

Trends and changes in maximum temperatures

Maximum air temperatures of both Girne and Lefkoşa stations have tended to increase in all seasons except in spring for Girne station (Figure 5,6). Increasing trends at Lefkoşa station started earlier than at Girne except in winter, in which both has a very similar temporal pattern. Observed increasing trends in maximum temperature series, however, are statistically significant only in summer and autumn seasons at Lefkoşa station. Warming trend is most pronounced for summer maximum temperatures of Lefkoşa, which is statistically significant in terms of both M-K and Sp tests and Student's t test made for LSLR approach (Table 2,3). Summer maximum temperatures of Lefkoşa are significant at the 0.01 level of significance according to Student's t test (Table 3).

Even though long-term increasing trends in maximum temperatures of Girne station are not statistically significant, some change points were determined in 1993 for winter and 1998 for autumn, all of which did not reach any significant period of warming (cooling) (Figure 5 (a, d)). As for the Lefkoşa station, change points were detected in 1993 for winter, in 1985 for spring and in about mid-1990s for summer and autumn (Figure 6 (a, b, c, d)). Only the trends of spring and summer maximum temperatures have reached a warming period very recently at the end of the series. Consequently, there is a need of further time period or years to adjust these increasing trends observed at the end of the series whether they would continue or not in the future.

Trends and changes in minimum temperatures

The strongest and the systematic secular increasing trends are dominant in the seasonal minimum air temperatures in Northern Cyprus. All minimum temperature series of Girne and Lefkoşa stations have been clearly characterized by a long-term systematic increasing trend (Figure 7, 8). Particularly the warming trends in summer and autumn seasons are almost purely linear type at both stations (Figure 7,8 (c, d)). These observed long-term increasing trends at Girne and Lefkoşa stations are statistically significant for all trend tests at the 0.01 level of significance (Table 2, 3). Indeed, statistical probability of the resultant test statistics from all trend tests used in the study are less than 0.001 for both stations in all seasons except in winter.

In addition to the strong and significant secular trends in the seasonal series of Girne, apparent change points were located in 1993 for winter and spring, 1990 for summer and 1989 for autumn (Figure 7 (a, b, c, d)). Warming trends in these series also reach 0.95 level of confidence at about those years becoming a significant warming period of minimum temperature series. The significant warming periods have proved us existing of significant change in minimum temperatures of Girne station. It is also very likely that these significant changes are very difficult to be reversed, at least based on these recent air temperature observations. Similar spatial patterns are seen in minimum air temperatures of Lefkoşa station in comparison with Girne station. Only differences found are in the beginning of the change points and thus following warming periods. Change points were detected in 1994 for winter, in 1984 for spring, and in 1991 and 1992 for summer and autumn seasons (Figure 8 (a, b, c, d)).

Trends and changes in precipitation

Normalized seasonal precipitation series of Girne and Lefkoşa stations are statistically random against to any trend from all trend tests (Table 2, 3) and serial correlation from W-W test, in all seasonal series except in spring series of Lefkoşa (Table 4). On the other hand, even though they are not significant, normalized spring precipitation at Girne has tended to decrease apparently (Figure 9 (2a-b)), while normalized summer precipitation has revealed an apparent increasing trend at the Lefkoşa station (Figure 10 (3a-b)).

Winter precipitation anomaly series of Girne station have indicated an increase in recent years following a considerable dry (drier than long-term average) period 1993-2000 (Figure 9 (1a-b)). Inter-annual variations of summer precipitation series are characterized by a fluctuation on a stable long-term average (Figure 9 (3a-b)), while variations in autumn precipitation series are also climatologically and statistically random against to any trend and serial correlation (Figure 9 (4a-b)).

As for Lefkoşa station, in addition to an apparent but in-significant increasing trend in normalized summer precipitation series (Figure 10 (3a-b)), normalized winter and spring precipitation series tended to increase in recent years from about 1999 to 2003 (Figure 10 (1a-b, 2a-b)). In spring, while a low-frequency fluctuation was dominant over the period 1975-1988, following period was characterized by an increased year-to-year variability (Figure 10 (2a-b)). Summer precipitation series have tended to increase slightly, and increased precipitation conditions were evident after the change point in 1992 (Figure 10 (3a-b)).

Conclusions

1) ***Mean temperatures***: Seasonal mean temperatures of Northern Cyprus have indicated an apparent increasing trend at Girne. According to the

results from M-K $u(t)$, Sp $u(r_s)$ and Student's t tests, these observed warming trends are statistically significant at the 0.01 level in all seasons except that in spring. The beginning point of the significant change on the series of Girne was detected in 1990 for winter and 1993 for summer and autumn seasons. The period of significant warming began in the mid-1990s for winter and summer immediately after the change point, and in the late 1990s for autumn.

2) ***Maximum temperatures***: Maximum air temperatures of Girne and Lefkoşa stations have tended to increase in all seasons except in spring at Girne. Nevertheless, observed warming trend is most pronounced for summer maximum temperatures of Lefkoşa, which is statistically significant according to all trend tests. Even though long-term increasing trends in maximum temperatures of Girne station are not significant except in summer, change points were found in 1993 for winter and 1998 for autumn. As for Lefkoşa, change points were detected in 1993 for winter, in 1985 for spring and in about mid-1990s for summer and autumn. Spring and summer maximum temperatures have reached a period of warming very recently at the end of the series.

3) ***Minimum temperatures***: The strongest and the systematic long-term increasing trends were detected in minimum air temperatures over Northern Cyprus. All minimum temperature series of Girne and Lefkoşa are evidently characterized by a long-term systematic increasing trend. These systematic increasing trends at Girne and Lefkoşa are statistically significant for all trend tests at the 0.01 level. Apparent change points at Girne were located in 1993 for winter and spring, 1990 for summer and 1989 for autumn. Warming trends in these series reached a significant period of warming at about those years. Similar spatial patterns are seen at Lefkoşa compared with Girne. Only differences found were in the timing of the change points and thus length of following warming periods. Change points were detected in 1994 for winter, in 1984 for spring, and in 1991 and 1992 for summer and autumn.

Results summarized above detected for Northern Cyprus have shown an close similarity with the results of the studies performed for some Mediterranean countries, for example, such as Spain (Esteban-Parra et al., 1995), southern Cyprus (Price et al., 1999), Israel (Ben-Gai et al., 1999), Italy (Brunetti et al., 2000) and Turkey (Türkeş et al., 2002).

4) ***Precipitation***: Normalized seasonal precipitation series of Girne and Lefkoşa stations have not revealed any statistically significant trend in all seasons, and serial correlation in all season with the exception of spring series recorded at Lefkoşa. Even though they are not significant, normalized spring precipitation of Girne has tended to decrease apparently, while normalized summer precipitation of Lefkoşa has indicated an apparent increasing trend. On the other hand, winter precipitation of Girne has shown an increase in recent years following a considerable dry period occurred during the period 1993-2000. In addition to an apparent but in-significant increasing trend in summer, winter and spring precipitations of Lefkoşa tended to increase during the period 1999 to 2003. Increased precipitation conditions in summer were also evident after the change point in 1992.

Table 1. Detailed climate types of Northern Cyprus according to Thornthwaite's climate classification.

Station	Moisture index (L_m)	Thermal efficiency	Humidity index (I_h)	Summer concentration (%)	Climate type with symbols
Girne	-26.3	103.4	14.5	50.0	*D*, *B*'$_4$, *d*, *b*'$_4$
Lefkoşa	-41.6	102.8	0.8	60.0	*E*, *B*'$_4$, *d*, *b*'$_2$

Table 2. Resultant test statistics and their significance levels from Mann-Kendall and Spearman rank correlation tests for seasonal average air temperatures (°C) and normalized seasonal precipitation anomalies of Girne and Lefkoşa stations.

	Winter				Spring			
STATIONS/Variables	Mann-Kendall		Spearman		Mann-Kendall		Spearman	
GİRNE	$u(t)$	P	$u(r_s)$	P	$u(t)$	P	$u(r_s)$	P
Mean temperature	3.6**	0.000	3.2**	0.001	1.79	0.073	1.94	0.052
Maximum temperature	1.54	0.124	1.66	0.097	0.49	0.624	0.61	0.542
Minimum temperature	3.97**	0.000	3.77**	0.000	4.63**	0.000	4.18**	0.000
Precipitation	0.20	0.841	-0.05	0.960	-1.73	0.084	-1.57	0.116
LEFKOŞA								
Mean temperature	-0.34	0.734	-0.30	0.764	-0.20	0.841	-0.27	0.787
Maximum temperature	0.88	0.379	1.21	0.230	1.56	0.119	1.61	0.107
Minimum temperature	2.81**	0.005	2.77**	0.004	4.15**	0.000	3.72**	0.000
Precipitation	-0.59	0.555	-0.70	0.484	-0.43	0.667	-0.29	0.772
	Summer				Autumn			
STATIONS /Variables	Mann-Kendall		Spearman		Mann-Kendall		Spearman	
GİRNE	$u(t)$	P	$u(r_s)$	P	$u(t)$	P	$u(r_s)$	P
Mean temperature	4.11**	0.000	3.36**	0.001	2.98**	0.003	2.80**	0.005
Maximum temperature	1.61	0.107	1.35	0.177	1.43	0.153	1.72	0.085
Minimum temperature	5.57**	0.000	4.74**	0.000	5.27**	0.000	4.59**	0.000
Precipitation	-0.36	0.719	-0.37	0.711	0.75	0.453	0.75	0.453
LEFKOŞA								
Mean temperature	1.84	0.066	1.57	0.116	-0.04	0.992	-0.20	0.841
Maximum temperature	2.19*	0.029	2.35*	0.019	1.66	0.097	1.90	0.057
Minimum temperature	5.26**	0.000	4.60**	0.000	4.27**	0.000	3.95**	0.000
Precipitation	1.61	0.107	1.63	0.103	0.41	0.968	0.39	0.697

(*) Statistically significant trend at the 0.05 level of significance.(**) Statistically significant trend at the 0.01 level of significance.

Table 3. Resultant test statistics and their significance levels from least-square linear regression approach and Student's *t* test for significance of estimated β coefficient, respectively, for seasonal average air temperatures (°C) and normalized seasonal precipitation anomalies of Girne and Lefkoşa stations.
(*) Statistically significant trend at the 0.05 level of significance.(**) Statistically significant trend at the 0.01 level of significance

STATIONS /Seasons	Mean temperature		Maximum temperature		Minimum temperature		Total precipitation	
GİRNE	*u(r)*	*P*	*u(r)*	*P*	*u(r)*	*P*	*u(r)*	*P*
Winter	-2.63	0.004**	0.44	0.330	-1.72	0.043*	-0.11	0.456
Spring	-1.58	0.057	0.82	0.206	-2.10	0.018*	0.13	0.448
Summer	-2.72	0.003**	-1.53	0.063	-3.54	0.000**	1.26	0.104
Autumn	-3.74	0.000**	-1.01	0.156	-3.45	0.000**	0.84	0.201
LEFKOŞA	*u(r)*	*P*	*u(r)*	*P*	*u(r)*	*P*	*u(r)*	*P*
Winter	-2.16	0.015*	0.54	0.295	0.17	0.433	-1.09	0.131
Spring	-1.78	0.038*	-1.03	0.152	-1.74	0.041*	-2.14	0.016*
Summer	0.13	0.448	-0.50	0.309	-2.90	0.002**	0.83	0.203
Autumn	-0.29	0.386	-1.56	0.059	-2.21	0.014*	1.49	0.068

Table 4. Resultant test statistics and their significance levels from Wald-Wolfowitz serial correlation test for seasonal average air temperatures (°C) and normalized seasonal precipitation anomalies of Girne and Lefkoşa stations.

STATIONS /Variables	Winter		Spring		Summer		Autumn	
GİRNE	*β*	Student *t*	*β*	Student *t*	*β*	Student *t*	*β*	Student *t*
Mean temperature	0.074	4.38**	0.028	1.84	0.066	4.91**	0.059	4.306**
Maximum temperature	0.039	1.55	0.013	0.62	0.025	1.34	0.033	1.957
Minimum temperature	0.092	4.66**	0.106	7.19**	0.163	10.7**	0.112	9.096**
Precipitation	1.395	0.45	-2.073	-2.14*	0.002	0.01	0.653	0.558
LEFKOŞA	*β*	Student *t*	*β*	Student *t*	*β*	Student *t*	*β*	Student *t*
Mean temperature	-0.006	-0.43	-0.014	-0.97	0.012	0.99	-0.006	-0.510
Maximum temperature	0.034	1.14	0.040	1.66	0.048	2.84**	0.037	2.081*
Minimum temperature	0.056	2.81**	0.090	4.92**	0.115	9.73**	0.084	5.648**
Precipitation	-0.038	-0.03	0.112	0.14	0.810	2.04	0.483	0.561

(*) Statistically significant serial correlation coefficient at the 0.05 level of significance
(**) Statistically significant serial correlation coefficient at the 0.01 level of significance

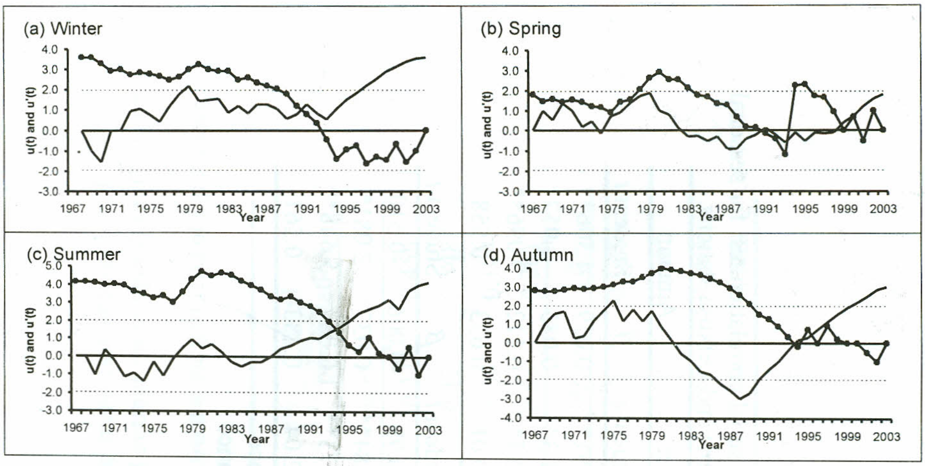


Figure 3. Trends in seasonal averages of mean temperature series at Girne station according the values of $u(t)$ (—) and $u'(t)$ (—•—) statistics from the sequential analysis of Mann-Kendall rank correlation method, with critical value of ± 1.96 (......) at the 0.05 level of significance in accordance with Gaussian distribution.

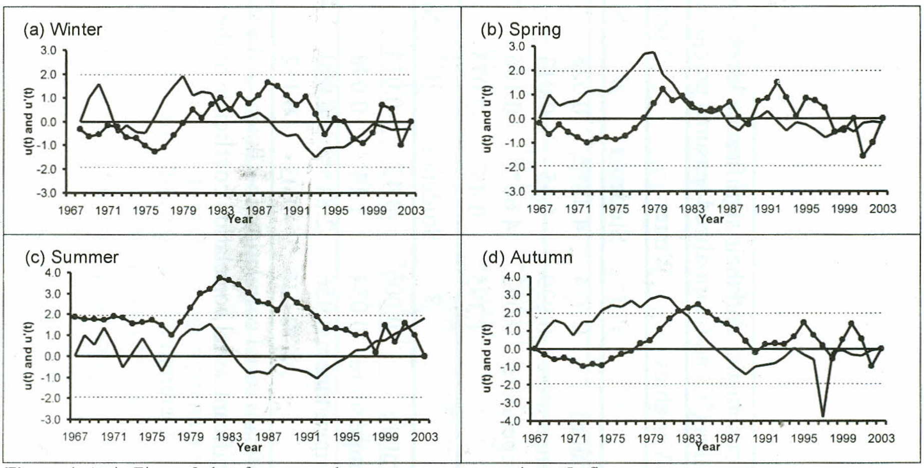


Figure 4. As in Figure 3, but for seasonal mean temperature series at Lefkoşa.

Trends and changes in mean temperatures

Based on the resultant test statistics from three trend tests applied to seasonal mean air temperatures recorded at Girne and Lefkoşa stations during the period 1967 (1968 for winter) to 2003, it is seen that seasonal mean temperatures indicate an apparent increasing trend at Girne (Figure 3). According to

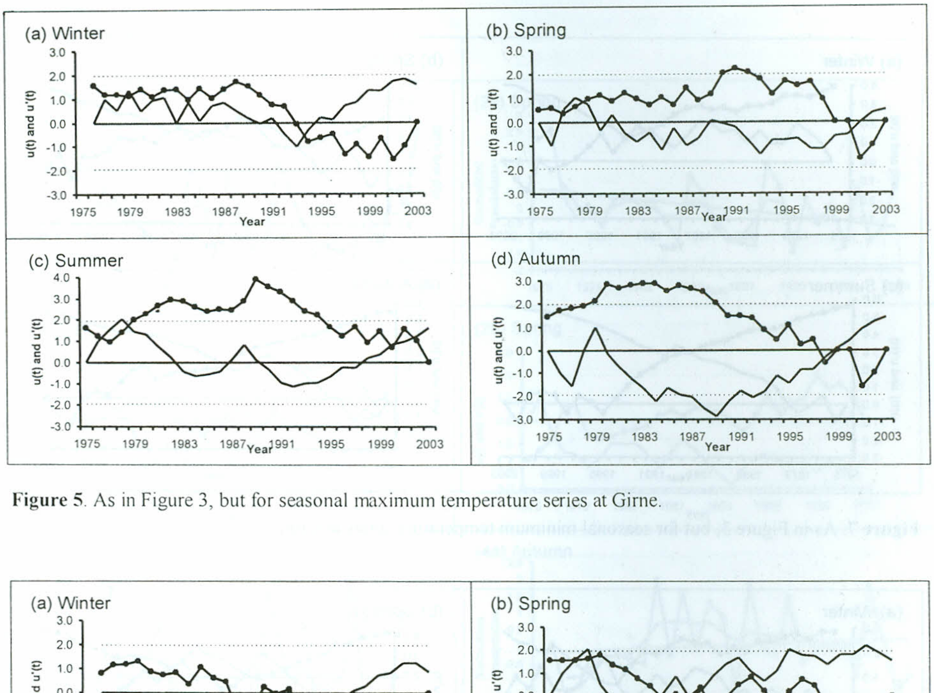


Figure 5. As in Figure 3, but for seasonal maximum temperature series at Girne.

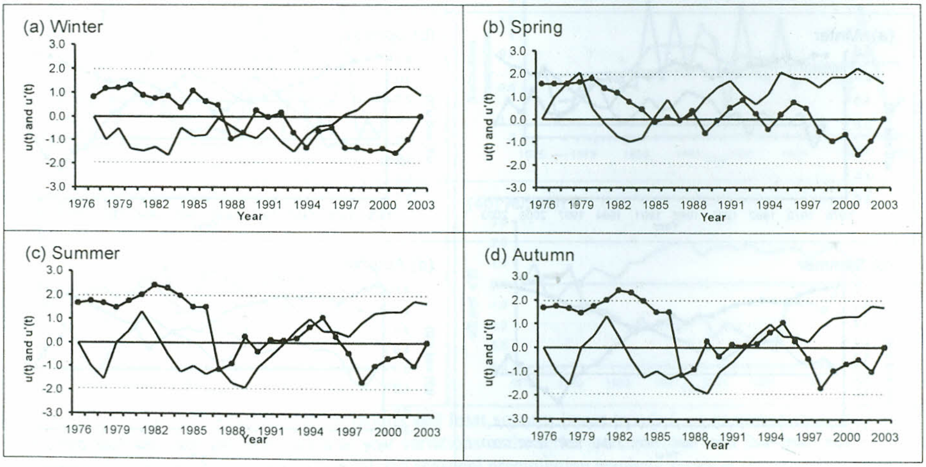


Figure 6. As in Figure 3, but for seasonal maximum temperature series at Lefkoşa.

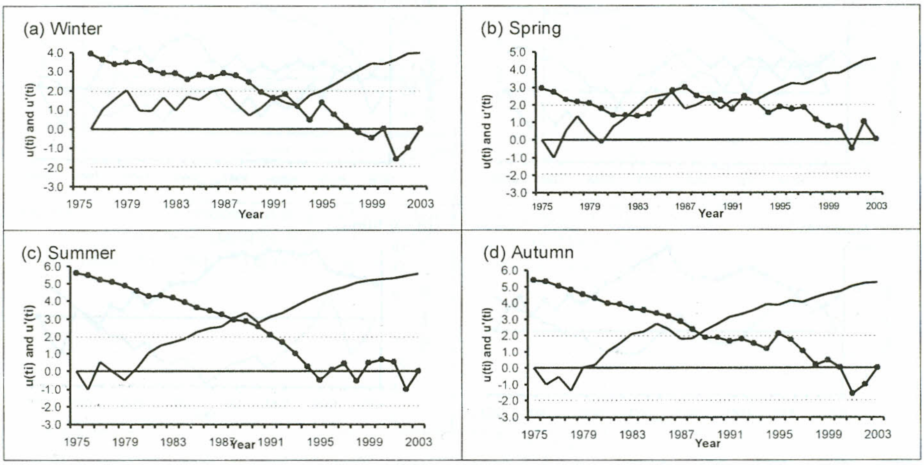


Figure 7. As in Figure 3, but for seasonal minimum temperature series at Girne.

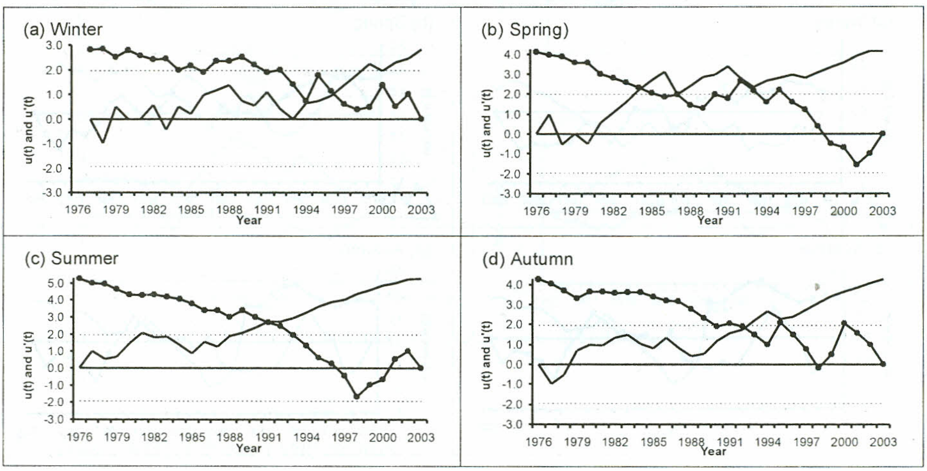


Figure 8. As in Figure 3, but for seasonal minimum temperature series at Lefkoşa.

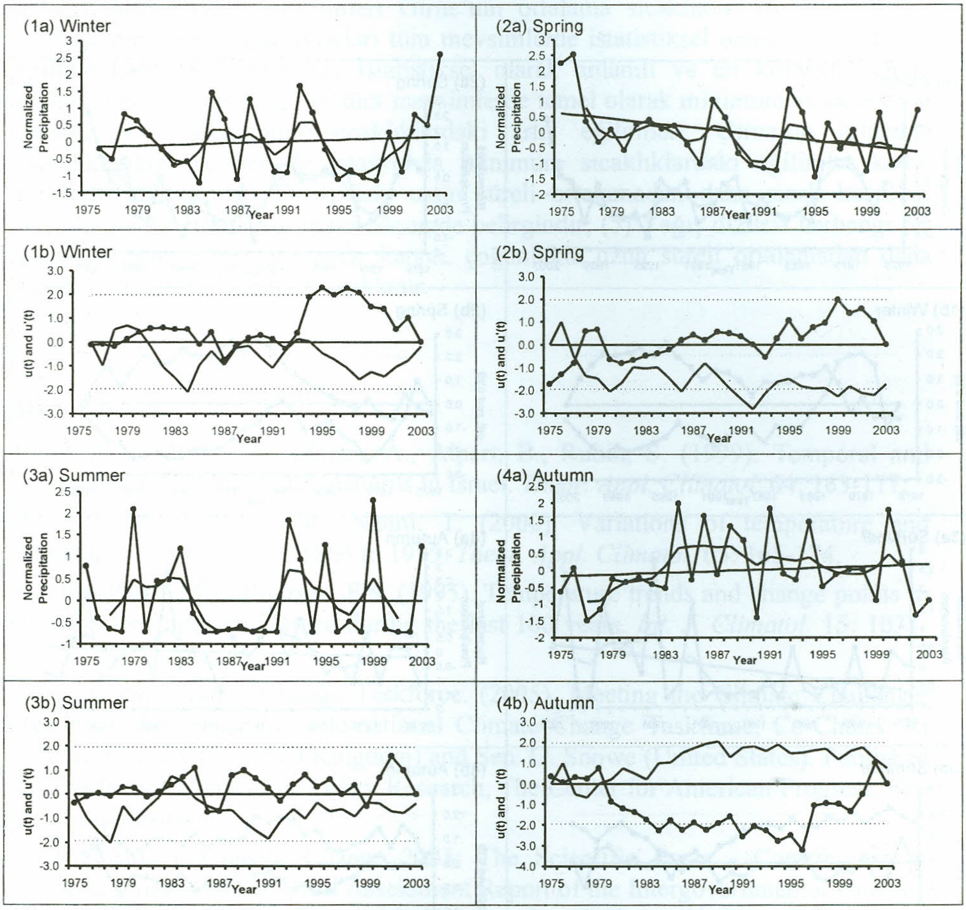


Figure 9. (1a, 2a, 3a, 4a): Year to year variations and least squares linear trends (—) in normalized seasonal precipitation anomaly series at Girne. Year to year variations in the series are smoothed with five-point Gaussian Filter (**—**). (1b, 2b, 3b, 4b): Trends in normalized seasonal precipitation anomaly series at Girne according the values of $u(t)$ (—) and $u'(t)$ (—•—) statistics from the sequential analysis of Mann-Kendall rank correlation method, with critical value of ± 1.96 (......) at the 0.05 level of significance in accordance with Gaussian distribution.

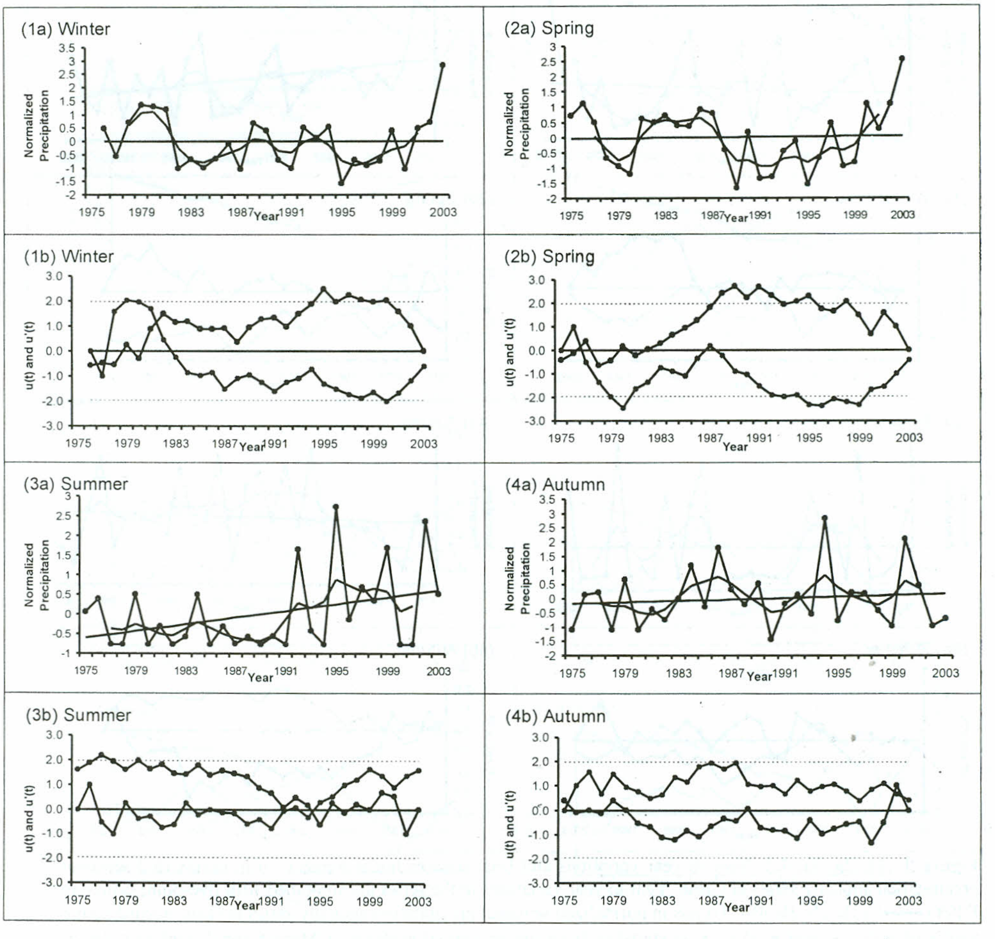


Figure 10. As in Figure 9, but for normalized seasonal precipitation anomaly series at Lefkoşa.

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Özet

Çalışmada, Kuzey Kıbrıs'ta bulunan Girne ve Lefkoşa istasyonlarının, mevsimlik sıcaklık ve yağış dizilerindeki uzun dönemli eğilimler ve değişimler araştırıldı. Çalışmanın önemli sonuçları aşağıdaki gibi açıklanabilir: (1) İstatistiksel olarak anlamlı artış (ısınma) eğilimleri Girne'nin ortalama sıcaklıklarında bulunurken, Lefkoşa'nın ortalama sıcaklıkları tüm mevsimlerde istatistiksel olarak herhangi bir eğilime karşı rasgeledir; (2) İstatistiksel olarak anlamlı ve en kuvvetli ısınma eğilimi, her iki istasyonda ve tüm mevsimlerde temel olarak minimum sıcaklıklarda görülür; (3) Maksimum sıcaklıklardaki artış eğilimleri, Girne'de ortalama sıcaklıklardaki ve her iki istasyonda minimum sıcaklıklardaki eğilimler kadar kuvvetli değildir; (4) Dizilerdeki uzun süreli ortalamadan daha sıcak koşullar, özellikle 1990 yılından sonraki dönemde belirgindir; (5) Yağış dizileri herhangi bir anlamlı eğilim göstermemesine karşın, çoğunlukla uzun süreli ortalamadan daha kurak ya da nemli koşullarla açıklanır.

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