ANNUAL AND SEASONAL TREND PATTERNS OF CLIMATE CHANGE IN NORTH CYPRUS

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ABSTRACT

ANNUAL AND SEASONAL TREND PATTERNS OF CLIMATE CHANGE IN NORTH CYPRUS

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In order to meet water needs for the present and future to sustain life, applying sustainable water resources management is vital. Changes in temperature and precipitation regimes affect the agriculture and ecosystem. Therefore, investigation of the changes in the spatial and temporal rainfall and temperature patterns is important for sustainable water resources management. The meteorological data used in this study was obtained from North Cyprus Meteorological Office. Annual, seasonal, and monthly rainfall variables are studied in order to examine the changes in precipitation regimes, while average and maximum of monthly maximum, average and minimum of monthly minimum, average of monthly average, and monthly diurnal temperature variables are used for the study of temperature regimes. Non-parametric Mann-Kendall rank correlation, Seasonal Kendall, Sen's T, and Seasonal Sen's T tests are employed to identify the existence of linear trend in rainfall and temperature variables. 10% significance level is used to extract significant trends. After filling in missing data and testing for homogeneity of time series for the period of 1978-2011, these trend tests are applied to the observed rainfall data from 20 rain-gauge stations, and temperature data from 8 temperature-gauge stations, all located in the northern part of the island. Inverse Distance Method has been used to fill in the missing values in the temperature and precipitation data. Furthermore, Standard Normal Homogeneity Test (SNHT) is employed in this study to determine the non-homogeneities in the data. The results show that there is no non-homogeneity in the records of both temperature and precipitation variables. Trend tests indicate that there is no trend in the annual rainfall. However, upward trends in

September rainfall and downward trends in March rainfall have been observed in most of the stations. This indicates that there is a shift in monthly rainfall regime. On the other hand, there are strong increasing trends in temperature variables, except downward trends in monthly diurnal temperatures. These upward trends have been observed mostly in summer months and almost in all stations. Diurnal temperature range indicates the differential value between average maximum and minimum temperatures. Since trends in average minimum temperatures have increased at a faster rate, decreasing trends have been observed in Diurnal temperature ranges in most of the stations. Trends in more extreme temperature variables, minimum of monthly minimum and maximum of monthly maximum temperatures, also increased during the period mostly in summer season, although the trends are not strong as the trends in the other temperature variables.

Keywords: Rainfall and temperature trend analysis, Mann-Kendall Trend test, Seasonal Kendall test, Sen’s T test, Seasonal Sen’s Ttest, North Cyprus.

ÖZ

KUZEY KIBRIS’TA YILLIK VE MEVSİMSEL İKLİM DEĞİŞİKLİĞİ TRENDLERİ

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Hayatın devamlılığı için gerekli su ihtiyacının karşılanabilmesi için su kaynaklarının sürdürülebilir şekilde yönetimi hayati önem taşımaktadır. Sıcaklık ve yağış rejimlerindeki değişiklikler tarım ve ekosistemi etkilemektedir. Bu sebepten dolayı, mekansal ve zamansal yağış ve sıcaklık verileri ile yapılan araştırmalar sürdürülebilir su yönetimi için çok büyük önem taşımaktadır. Bu çalışmada kullanılan meteorolojik veriler K.K.T.C. Meteoroloji Dairesinden temin edilmiştir. Yağışlardaki değişiklikleri çalışmak için yıllık, aylık ve mevsimlik yağış verileri dikkate alınmıştır. Sıcaklıklardaki değişiklikler için ise en yüksek aylık verilerin en yüksek ve ortalama değerleri, en düşük aylık verilerin en düşük ve ortalama değerleri, aylık ortalamaların ortalama değerleri ve ortalama en yüksek ve ortalama en düşük verilerin farkı çalışılmıştır. Sıcaklık ve yağış değerlerindeki trendler parametrik olmayan Mann-Kendall, Seasonal Kendall, Sen’s T ve Seasonal Sen’s T yöntemleri kullanılarak elde edilmiştir. Kayda değer bir trend olup olmadığını belirlemek için ise %10 önem düzeyinde çalışma yapılmıştır. Eksik verilerin doldurulması ve homojenlik testinin ardından yukarıda bahsedilen trend testleri Kuzey Kıbrıs’taki 20 yağış ve 8 sıcaklık istasyonlarından elde edilen 1978’den 2011 yılına kadar olan verilere uygulanmıştır. Inverse Distance Method yağış ve sıcaklık verilerindeki eksik kısımların doldurulmasında kullanılmıştır. Daha sonra, kullanılacak olan verilerin homojen olduğundan emin olabilmek için Standard Normal Homogeneity Test (SNHT) kullanılarak homojenlik testi yapılmıştır. Elde edilen sonuçlara göre analizlerde kullanılacak olan sıcaklık ve yağış verilerinin homojen olduğu ortaya çıkmıştır. Yapılan trend çalışmaları sonucunda yıllık yağışlarda bir değişiklik gözlenmezken, Eylül ayındaki yağışlarda artma ve Mart ayındaki yağışlarda azalma gözlenmiştir.

Buda bize toplam yağışlarda bir değişiklik olmaması ile birlikte aylık yağışlarda bir kayma olduğunu göstermektedir. Bunun yanı sıra, birçok istasyonda sıcaklık trendlerinde özellikle yaz aylarında ciddi artışlar olduğu belirlenmiştir. Ortalama en düşük sıcaklıklardaki değişikliklerin ortalama en yüksek sıcaklıklardakine oranla daha yüksek olmasından dolayı aralarındaki farklarda azalmalar gözlemlenmiştir. En uç sıcaklık değerlerinde de, en düşük/yüksek uç sıcaklıklarda, diğer verilerdeki şiddetle olmasa da artış gözlemlenmiştir

Keywords: Yağış ve sıcaklık trend analizleri, Mann-Kendall trend testi, Seasonal Kendall testi, Sen’s T test ve Seasonal Sen’s T test, Kuzey Kıbrıs.

To My Parents

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

a	Most probable time point of change or the last time point of the sub-series withmean $\overline{z_1}$
d	Distance from the location of gauged station to the ungauged station
H_o	Null hypotheses
H_1	Alternative hypotheses
k	Total number of reference stations
n	Length of the data set
m	Number of surrounding stations
N	Number of surrounding stations
N_i	Normal annual precipitation of surrounding stations
N_x	Normal annual precipitation of X station
P_x	Estimate of rainfall for the ungauged station
P	Rainfall values of rain gauges used for estimation
Q_i	Difference and ratio between the candidate and reference series at time step *i.*
Q	Mean values of Q_i series
S	Mann-Kendall test statistic
T	Standard normal homogeneity test statistic
T	Number of ties of extent
V_j	Square of the correlation coefficient between the candidate and a Reference station
X_{ji}	Reference series (the $j^{th}$of a total of k)
X_j	Mean values of the X series
X_i	Data values at times i
x_j	Data values at times j

Y_i	Candidate series at year i (or other time unit)
Y	Mean valus of Y series
Z_i	Standardized series with zero mean and unit standard deviation
$\overline{z_1}$	Averages of the Z_i sequences before the shift
$\overline{z_2}$	Averages of the Z_i sequences after the shift
Z	Standardized test statistic
R_{ij}	Matrix of ranks
$R_{.j}$	The ranks for each month
$R_{.i}$	The ranks for each year

CHAPTER I

INTRODUCTION

The effects of climate change, which is formed as a result of the increased greenhouse gases in the atmosphere over the 20th Century, have been analyzed by many researchers. As several extreme events in recent years have caused large losses of life and property, the alarm over the possibility that these events were due to climate change is increased (Easterling et al., 2000). It has been documented that increased greenhouse gas concentration in the atmosphere has resulted in the increase of the global average surface temperature by about 0.74°C from 1906 to 2005 (IPCC, 2007). According to the Special Report on Emissions Scenarios (SRES) scenarios, it has been projected that there will be warming about 0.2°C per decade for the next two decades. It has further been documented that significantly increased precipitation has been observed in eastern parts of North and South America, northern Europe and northern and central Asia. There is a possibility that increased atmospheric temperature is related with an increase in heavy precipitation due to an increase in atmospheric water vapour and the warmer air (IPCC, 2007). As global average temperature increases about 1.5 to 2.5°C, projections suggest that there will be significant extinctions with about 20 to 30% of species. In addition, if global average warming reaches about 3.5°C, it is suggested that 40 to 70% of species are likely to be at risk of extinction (IPCC, 2007). The effects of climate change have been analyzed in many studies with focusing on precipitation and surface air temperature (Feidas et al., 2004; Kostopoulou and Jones, 2005; Luterbacher et al., 2004; Partal and Kahya, 2006; Kysely 2009; and Clark, 2000).

1.1 Problem Statement

The hazards like floods and droughts that may be linked to climate change have recently been experienced more frequently in North Cyprus like in the other parts of the world. Cyprus, as a third largest island in the Mediterranean Sea, is located at the South of Turkey and West of Syria and Lebanon. With a semi-arid climate, the only source of water in the island is rainfall. Therefore, changes in rainfall regime directly affect the water resources management and ecosystem in the island.

1.2 Objective of the Research

In order to improve water management strategies which are important for agriculture, it is vital to investigate the changes in the rainfall and temperature patterns. Thus, the main objective of this study is to determine whether there is an evidence of significant trends in precipitation and surface air temperature across North Cyprus. This and further studies will contribute to the researches about the effects of climate change in the Mediterranean region. The results will also quide government and citizens in North Cyprus to take precautions about the changes in rainfall and temperature.

1.3 Organization of the Thesis

The organization of the thesis is as follow :

- Chapter 1 presents the introduction, objectives of the study and scope of the thesis.
- Chapter 2 gives information about the trend analysis in the literature in Mediterranean region, Turkey and the other part of the world
- Chapter 3 explains analyses which include filling in missing data, determination of non-homogeneities, and trend detection.
- Chapter 4 includes description of meteorological data.
- Chapter 5 gives the results and discussions.
- Chapter 6 includes the conclusions derived from this study.

CHAPTER II

LITERATURE REVIEW

The hazards like floods and droughts that may be linked to climate change have recently been experienced more frequently in the world. Midwest-drought of 1988-1989, Hurricane Andrew in South Florida in 1992 and the Midwest flood of 1993 can be given as an example (Easterling et al., 2000). Therefore, it is vital to make study related to the climate change. The effects of climate change have been analyzed in many studies throughout the world with focusing on different hydro-meteorological variables such as precipitation, surface air temperature, and streamflow (Feidas et al., 2004; Kostopoulou and Jones, 2005; Luterbacher et al., 2004; Partal and Kahya, 2006; and Kahya and Kalaycı, 2004). In this chapter, studies about the trend analysis in Mediterranean region, Turkey, and the other parts of the world are discussed in the given order.

2.1 Trend Analysis in Mediterranean Region

The number of trend analysis of meteorological and hydrological variable over the Mediterranean region is available in the literature. For example, Feidas et al. (2004) studied trends in the annual and seasonal surface air temperature for 20 stations in Greece from 1955 to 2001, and for satellite data from 1980 to 2001. Least square method and Mann-Kendall test were used in this study. It was found that there were no significant trends for annual values. However, results for satellite data indicated that there was a remarkable warming trend in mean annual, winter and summer in Greece. Kostopoulou and Jones (2005) analyzed trends over the eastern Mediterranean region for precipitation and temperature data related climate extremes. The study period is from 1958 to 2000. Linear regression analysis and Kendall-tau rest were used during the trend analysis. It was found that there were significant warming trends during summer in temperature indices. Significant positive precipitation trends were also seen for central Mediterranean region, while eastern half of the study region shows negative trends in all precipitation indices. Alpert et al. (2002) examined 265 stations for six different daily rainfall categories, light, light-moderate, moderate-heavy, heavy, heavy-torrential, and torrential, in the Mediterranean region. Spain (182 stations), South Cyprus (3 stations), Italy (42 stations) and Israel (38 stations) were examined in the region for the period 1951-

1995. It was indicated that there was a paradoxical increase in the extreme daily rainfall, although there was a decrease in the total rainfall. The study of Yosef et al. (2009) examined six daily rainfall categories for 32 stations across Israel from January 1950 to April 2003 with using Pearson and Spearman’s tests. Some of the stations showed a significant increase in the heavy to torrential daily rainfall. On the other hand, any significant change in the annual rainfall was not seen.

According to the studies given above, it can be concluded that there were warming trends mostly in summer in temperature indices in the Mediterranean region. Although increasing trends have been observed in some of the rainfall variables, there are decreases or no changes in the total rainfall.

2.2 Trend Analysis in Turkey

There are also many studies in Turkey about trends in hydroclimatologic variables. For example, Kadıoğlu (1997) studied trends in the surface air temperature with using Mann-Kendall rank statistic for 18 stations across Turkey. It was indicated that there was an increasing trend in mean annual temperatures over the period of 1939-1989 but a decreasing trend from 1955 to 1989. However, it was also indicated that these trends were not statistically significant. Kahya and Kalaycı (2004) analysed trends in monthly streamflows over Turkey from 1964 to 1994. Four different trend tests which are Sen’s T, Spearman’s Rho, Mann-Kendall, and Seasonal Kendall were used. According to their results the river basins located in western Turkey demonstrated downward trends for streamflow variable, while there were no significant trends in the basins located in eastern Turkey. In another study, Partal and Kahya (2006) performed trend tests with using Mann-Kendall and Sen’s *T* tests for 13 hydrologic variables, annual mean precipitation and monthly total precipitation, across Turkey for a period covering 1929-1993. It was found that there were strong downward trends in annual mean, January, February, and September precipitations. The other variables showed both decreasing and increasing trends, and most of the decreasing trends were in western and southern parts of Turkey. According to the studies of Kahya and Kalaycı (2004) and Partal and Kahya (2006), it can be said that the reason of the decreasing streamflow in western Turkey is most likely due to the decreasing precipitation in the same region.

The studies in Turkey showed that there are regional and periodical differences for trend results, and there is a relation between hydroclimatologic variables. For longer period, warming trend in temperature has been observed, while there are decreasing trends for shorter period. Depending on the decreases in precipitation in western Turkey downward trends in streamflow in the region has been observed.

2.3 Trend Analysis in Other Parts of the World

The trends in hydroclimatologic variables are also analysed in the other parts of the world. For example, Luterbacher et al. (2004) studied trends, variability, and extremes of the seasonal and annual temperature since 1500 for Europe. Mann-Kendall test was used for trend analysis. It was found that there was a warming trend in the climate of Europe in the late 20th and early 21st century over the past 500 years. There was a 0.5°C increase in the winter average temperatures for the period of 1500-1900 compared to the 20th century. In addition to these findings, it was also indicated that the coldest winter and hottest summer were in 1708 - 09 and 2003, respectively. Burn and Elnur (2002) stated the similarities in trends and patterns in the hydrological and meteorological variables at selected locations in Canada. They studied 18 hydrological variables for 248 Canadian catchments using Mann-Kendall test for a period of 1940-1997. The study implies that there was a relationship between the hydrological and meteorological variables. In the study of Vincent et al. (2005), scientists from eight South America countries undertook a study with daily climatological data from their region. The study was about the examination of the trends in the indices of daily temperature extremes from 1960 to 2000. Two-phase regression model was used in this study. Although it was found that there were no significant changes in the indices of daily maximum temperature, there were significant increasing trends in the indices of daily minimum temperature. Significant increasing and decreasing trends were observed in the percentage of warm nights, and cold nights respectively at many stations. Tabari et al. (2011) examined the trends of the annual maximum, minimum, and mean air temperature and precipitation time series from 1966 to 2005 in the west, south, and southwest of Iran. In this study, Mann–Kendall, Mann–Whitney, and Mann–Kendall rank statistic tests were used. The results indicated that there were warming trends in annual maximum, minimum, and mean air temperature. The results for precipitation series show various patterns (increasing and decreasing trends).

According to the studies across the world, it can be concluded that there are warming trends in temperature in the world.

CHAPTER III

METHODOLOGY

The data that is selected to be used in trend analysis should not have any missing parts, and should be homogenized for a sound analysis. Therefore, missing parts in the data are filled-in, and then homogeneities of recorded time series are tested using suitable methods before applying any trend tests.

There are different methods which were commonly used in literature for trend analysis, and generally they are divided into two groups as parametric and non-parametric tests (Burn and Elnur, 2002; Kahya and Kalayci, 2004; Belle and Hughes, 1984). In this study, non-parametric tests were selected to be used, because they have some advantages. Firstly, they are distribution free. They do not need any assumption about following normal or any other distribution. Parameters that are estimated using observed data, are not important like in parametric tests, while in non-parametric tests the relationship between the values is important. Secondly, non-parametric tests are simple to understand and easy to apply. They do not require complex computations and are less time-consuming (Aggarwal and Khurana, 2009).

The chapter is organized as follows. Section 3.1 gives methods for filling-in missing rainfall and temperature data. The method for homogenization of rainfall and temperature data is shown in Section 3.2. In Section 3.3, trend analyses methods are given. In the last section, conclusions for this chapter are provided.

3.1 Methods for Filling-in Missing Rainfall and Temperature Data

There might be lack of continuous data due to natural hazards (floods, hurricanes, etc.), human related problems (mistake in handling data, etc.) and others (Elshorbagy, 2000). The gaps in the data should be filled with using suitable methods. There are different interpolation techniques that are commonly used to fill-in the gaps (missing observations) in data (Salas, 2006; Silva et al., 2007). Among various techniques, Inverse Distance Method, Arithmetic Mean Method, and Normal

Ratio Method were compared to find the most suitable method for filling missing observations. The brief descriptions of these three methods are presented below.

3.1.1 Inverse Distance Method

In this method, weights for each sample are inversely proportionate to its distance from the point being estimated (Silva et al., 2007). Given the observed rainfall values of nearby rain gauges and the distance from the gauged stations to the ungauged station, the estimate of missing rainfall at ungauged station is possible by

$$P_x = \frac{\sum_{i=1}^{N} \frac{1}{d_i^2} p_i}{\sum_{i=1}^{N} \frac{1}{d_i^2}} \tag{1}$$

where P_x is the estimate of rainfall for the ungauged station, p_i is the rainfall values of rain gauges used for estimation, d_i is the distance from the location of gauged station to the ungauged station, and N is the number of surrounding stations.

3.1.2 Arithmetic Mean Method

This method is used when the *norma*l annual precipitations at surrounding gauges are within the range of 10% of the normal annual precipitation at station X (ungauged station). To estimate the missing values of station X, arithmetic mean of precipitation records of the surrounding stations is calculated. Because, the method assumes that there are equal weights from all nearby rain gauge stations (Salas, 2006 and Silva et al., 2007).

3.1.3 Normal Ratio Method

This method is applied, if the *normal* annual precipitation at surrounding gauged stations exceeding 10% of the considered gauge (not equal weights). As the method is applicable for daily, weekly, monthly, etc data, it is also applicable for any type of hydro-meteorological data such as temperature. The estimation of missing data at ungauged station is possible by

$$P_x = \frac{1}{m} \sum_{i=1}^{m} \left[\frac{N_X}{N_i} \right] P_i \tag{2}$$

where $P_{\times}$ is the estimate for the ungauged station, P_i is the rainfall values of rain gauges used for estimation, $N_{\times}$ is the normal annual precipitation of X station, N_i is the normal annual precipitation of surrounding stations and m is the number of surrounding stations (Salas, 2006 and Silva et al., 2007).

3.2 Methods for Homogenization of Rainfall and Temperature Data

Climatological records are often limited by degree of in-homogeneity of the data. The reason of this is logistic problems, such as station relocations and equipment drift. In addition, changes in measuring techniques and changes in the surroundings of a station, such as urbanization, may also cause in-homogeneity in the recorded data (Wijngaard et al., 2003; Khaliq and Quarda, 2007). For instance, tree growing in height can cause alterations in wind speed which can make changes in rainfall cathment efficiencies (Alexander and Moberg, 1997). Therefore, the second stage of the trend test studies should be the determination of the non-homogeneities in the data to develop homogenized records. Several methods have been developed for this purpose, such as Standard Normal Homogeneity Test (SNHT), (Swed–Eisenhart) Runs Test, and Pettitt Homogeneity Tests (Fırat et al., 2010 and Alexandessson and Moberg, 1997). Slonosky *et al.*(1999) used different methods to test the homogeneity for surface pressure series in Europe with 51 stations which consist of long years of observations and it was indicated that the SNHT method shows a good result when a suitable reference series is obtained for comparison-evaluation and correction. In addition, the SNHT method was used very commonly in the past studies (Tuomenvirta, 2002 and Wijngaard et al., 2003), therefore, the test was selected to be employed in this study as well.

3.2.1 Standard Normal Homogeneity Test (SNHT)

Standard normal homogeneity test (SNHT) was developed by Alexandersson (1986), and applied to precipitation data set from south-western Sweden. While the test was developed to examine in-homogeneities in the form of abrupt shifts in the mean value of the observations, it was then modified to have ability to test in-homogeneities in the form of linear time trends (Alexandessson and Moberg, 1997).

The first step of the test is to develop and document nearly true critical values of the SNHT statistics. The aim of this is to make correct conclusion with simplified usage of the test in practice (Khaliq and Quarda, 2007). Therefore, large sets of random normal numbers are used to simulate critical values. According to this test, Y_i (i= 1 ,…., n) is used to denote a candidate series at year i (or other time unit). X_j is used to denote one of the reference series (the j^{th} of a total of k), which are developed from a group of surroundings. In addition to these series, Q_i ($i=1,\ldots, n$) is developed to denote the difference (e.g. for temperature and pressure data) and ratio (e.g. for precipitation data) between the candidate and reference series at time step i (Khaliq and Quarda, 2007). The ratio and difference terms are formed as in Eq. (3) and Eq. (4), respectively.

$$Q_i = \frac{Y_i}{\left[\sum_{j=1}^{k} V_j X_{ji} \overline{Y} / \overline{X_j}\right] \Big/ \sum_{j=1}^{k} V_j} \tag{3}$$

$$Q_i = Y_i - \left\{ \sum_{j=1}^{k} V_j \left[X_{ji} - \overline{X_j} + \overline{Y} \right] \Big/ \sum_{j=1}^{k} V_j \right\} \tag{4}$$

where V_j denotes the square of the correlation coefficient between the candidate and a reference station. Bar denotes mean values, which is for X_j and Y series.

Standardized series are essential in the standard normal homogeneity tests. Because of that, standardization (Eq. (5)) of the Q_i series is performed to obtain a series Z_i (with zero mean and unit standard deviation).

$$Z_i = \left(Q_i - \overline{Q}\right) / \sigma_Q \tag{5}$$

where $\overline{Q}$ and σ_Q are the mean and standard deviation of the Q_i series, respectively.

The null and alternative hypotheses which are used to test whether there is a single shift in the mean level of the candidate series are expressed as

$$H_o : Z_i \sim N(0,1) \text{ for } i = 1,\ldots\ldots, n$$

$$H_1 : \begin{cases} Z_i \sim N(\mu_1,1) & \text{for} \quad i = 1,\ldots..a \\ Z_i \sim N(\mu_2,1) & \quad\quad\; i = a+1,\ldots.., n \end{cases} \tag{6}$$

Alexandersson and Moberg (1997) generated a test statistic based on the principle of likelihood ratio to test the validity of H_1 against H_o. This test statistic is given as

$$T = \max\left\{a\left(\overline{z_1}\right)^2 + (n-a)\left(\overline{z_2}\right)^2\right\}, \qquad 1 \le a \le n-1 \tag{7}$$

where $\overline{z_1}$ and $\overline{z_2}$ are the averages of the z_i sequences before and after the shift. The value of *a* corresponding to T is the most probable time point of change or the last time point of the sub-series with mean $\overline{z_1}$. If *T* is above the critical value of a certain critical level (e.g. 90%), then the null hypothesis of homogeneity can be rejected at the corresponding significance level (i.e. 10%) (Khaliq and Quarda, 2007).

3.3 Methods for Trend Analysis of Rainfall and Temperature

With increasing attention to climate change, trend tests of climatologic variables have become popular during the final quarter of the last century in environmental sciences. Among various trend analysis techniques, two non-parametric tests which are Mann-Kendall and Sen's T tests were selected to be used in this study. Mann-Kendall test was found to be an excellent tool for trend detection by other researchers in similar applications (Hirsch et al., 1982 and Gan, 1992). Although Mann-Kendall test is very good method for trend analysis, Sen's *T* test was also used in this study to obtain extra confidence. These methods were commonly used in the trend test studies in the literature (Douglas et al, 2000; Burn and Elnur, 2002; Kahya and Kalayci, 2004; Partal and Kahya, 2006; Kadioglu, 1997, Cannarozzo et al, 2006). In addition to these tests, Seasonal Mann-Kendall and Seasonal Sen's T tests were also used to test if there is trend in overall seasonal (monthly) meteorological time series.

3.3.1 Mann-Kendall Trend Test

The Mann-Kendall test is widely used to test for randomness against trend in hydrological and climatological time series (Kahya and Kalaycı, 2004). It has two parameters which are essential to detect trends. First of these parameters is significance level that indicates the trend's strength, and the second is the slope magnitude which indicates the direction and magnitude of the trend. First step of the test is the calculation of the Mann-Kendall test statistic, *S*. This value is used to determine whether there is a trend or not, and also to determine the direction of the trends according to the sign of the S value (Hirsch and Slack, 1984). If there is a trend, the significance of it should be examined. Because of that, standardized test statistic, Z, is computed with using variance and S values, which is then used in two sided test (Douglas et al., 2000). According to the significance level, Z values give information about the null hypothesis, H_o and alternative hypothesis, H_1. The null hypothesis, H_0, indicates that there is no trend, while alternative hypothesis, H_1, indicates that there is a trend in the analyzed dataset. Each step of the Mann-Kendall Test is presented below from Eq. (8) to (11).

Mann-Kendall test statistic, S, is calculated using Eq. (8) and (9):

$$S = \sum_{i=1}^{n-1} \sum_{j=i-1}^{n} Sgn(x_j - x_i) \tag{8}$$

where x are data values at times i and j, and n is the length of the data set.

$$Sgn(\theta) = \begin{cases} +1 & \text{if} \quad \theta > 0 \\ 0 & \text{if} \quad \theta = 0 \\ -1 & \text{if} \quad \theta < 0 \end{cases} \tag{9}$$

A positive value of S shows an upward trend, while negative value indicates downward trend.

The test statistic S, which is approximately normally distributed, has mean zero and a variance which is calculated by:

$$Var(S) = \begin{cases} \dfrac{\{n(n-1)(2n+5) - \sum_{j=1}^{p} (t_j - 1)(2t_j + 5)\}}{18}, & \text{if ties} \\ \dfrac{\{(n(n-1)(2n+5)\}}{18}, & \text{if} \quad \text{no} \quad \text{ties} \end{cases} \tag{10}$$

where *n* is the number of data, *p* is the number of tied groups in the data set and t_j is the number of data points in the *j*th tied group (Mozejko, 2012). For the sample size *n* larger than10*,* the standardized test statistic *Z* is computed as:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\mathrm{var}(S)}} & \text{if} \quad S > 0 \\ 0 & \text{if} \quad S = 0 \\ \dfrac{S+1}{\sqrt{\mathrm{var}(S)}} & \text{if} \quad S < 0 \end{cases} \tag{11}$$

Following this, two-sided test for trend is applied using the *Z* values, and if $|Z| \leq Z_{\alpha/2}$, H_o should thus be accepted. This means that there is no trend.

3.3.2 Seasonal Kendall Trend Test

If data contain seasonal variations, tests for trend should be done after removing these variables. Because of that, seasonal Kendall test was proposed by Hirsch, Slack, and Smith (Hirsch et al., 1982). Seasonal Kendall test is the generalized form of the Mann- Kendall test. According to the test, Mann-Kendall test statistic *S* and its variance should be computed separately for each month (season). Following this, these S values are summed, and Z values (similar to the Mann-Kendall test) are computed. Each step of the Seasonal Kendall Test is presented below from Eq. (12) to (14). The rest of the test is similar to that of the Mann-Kendall test (Kahya and Kalaycı, 2004; Mozejko, 2012).

Test statistic S_K is obtained by adding all *S* values associated to each month.

$$S_K = \sum_{i=1}^{K} S_i \tag{12}$$

Then the variance of S_K is calculated as

$$Var(S_K) = \sum_{i=1}^{K} Var(S_i) \tag{13}$$

After obtaining S_K and $Var(S_K)$ the test statistic *Z* is calculated as

$$Z = \begin{cases} \dfrac{S_K - 1}{\sqrt{\operatorname{var}(S_K)}} & \text{if} \quad S_K > 0 \\ 0 & \text{if} \quad S_K = 0 \\ \dfrac{S_K + 1}{\sqrt{\operatorname{var}(S_K)}} & \text{if} \quad S_K < 0 \end{cases} \tag{14}$$

As in the Mann-Kendal test, two-sided test for trend is applied using the *Z* values.

3.3.3 Sen's T Test

Sen's T test is an aligned rank method. At first, the block (effect of season) is removed from each time series. Secondly, the data over blocks (seasons) are summed to produce a statistic from these sums. This aligned rank method, which is more powerful than its counterpart (such as the Mann-Kendall test), is distribution free and not affected by seasonal fluctuations (Partal and Kahya, 2006). Following steps are applied in order:

1- The average for the month *j* and for the year *i* are computed by

$$X_j = \frac{\sum_i^n X_{ij}}{n} \quad \text{and} \quad X_i = \frac{\sum_i^m X_{ij}}{m} \tag{15}$$

2- The month average is subtracted from each of the corresponding months in the *n* years of data ("$X_{ij} - X_j$" is calculated for $i = 1,...,n$ and $j = 1,...,m$ to remove monthly or seasonal effects).

3- All differences obtained from step 2 are ranked from 1 to nm (number of months times the number of years) to obtain the matrix (R_{ij}).

4- The ranks for each year are averaged with; $R_{.i} = \sum_{j=1}^{12} R_{ij} \big/ 12$

5- The ranks for each month are averaged with; $R_{.j} = \sum_{i=1}^{n} R_{ij} \big/ n$

6- Test statistic is calculated by

$$T = \left[\frac{12m^2}{n(n+1)\sum_{i,j}(R_{ij} - R_j)^2} \right]^{\frac{1}{2}} \left[\sum_{i=1}^{n} (i - \frac{n+1}{2})(R_i \frac{nm+1}{2}) \right] \tag{16}$$

Significant trend exists in the time series, while $|T| > z_{\alpha}$.

Positive values of *T* denote an ‘upward trend’, while negative values of it indicate ‘downward trend’.

3.3.4 Seasonal Sen’s T Test

Seasonal Sen’s T Test was used to test if there is trend in overall monthly meteorological time series. Each step in this method is the same with the steps in Sen’s T Test, given in section 3.3.3. The only difference is the type of the data that is analysed. It is a matrix which includes all month’s values.

3.4 Conclusion for Methodology

Firstly, different methods for filling in the missing parts of the data were compared to find the most suitable method. Some of the observed values in the data were assumed as a missing value, and filled with using the methods given in section 3.1. According to the means of percent error, means of standard deviation, and the correlation coefficient between the true observed and filled values (Silva et al., 2007), it was decided that Inverse Distance Method is the most suitable method for the data of this study. Because, it was found that Inverse Distance Method has the smallest percent error, smallest standard deviation, and largest correlation coefficient. The reference stations according to their locations and their observed values at the corresponding time were selected for the Inverse Distance Method. Reference stations are the nearest stations to the candidate station and they are all in the same region of the candidate station. Distance between the reference and candidate stations were measured using Google Earth. The missing parts were then filled. Secondly, there is a possibility that the observed data can be affected from the external physical cases and this can affect the neutrality of the trends. Therefore, Standard Normal Homogeneity Test was used here to test the homogeneity of the data, and it was found that the data for each station is homogenous. Finally, trend tests were applied to the homogenous and continuous data. Non-parametric tests were selected to be used for trend analysis, which are Mann-Kendall, Seasonal Kendall, Sen’s T and Seasonal Kendall tests. *Z* values for Mann-Kendal / Seasonal Kendall tests and *T* values for Sen’s T / Seasonal Sen’s T tests were analyzed at 90% confidence interval. These values were also analyzed at 95% and 99% confidence intervals, and similar trends have been observed but at fewer stations. As the trends at 90% confidence interval enlighten more clearly the future regimes of temperature and precipitation, this one was selected to be used in this study. Trends were named as a significant trend, if both *Z* (Mann-Kendall) and *T* (Sen’s T test) values were bigger than the limiting value according to the selected confidence interval.

CHAPTER IV

METEOROLOGICAL DATA

The meteorological data that are used in this study were obtained from North Cyprus Meteorological Office. Two factors have been considered in the decision of meteorological gauge stations that will be considered in this study. The first decision was about the length of the observed data. In order to relay on the result of a statistical test, the observed data must be long enough. In statistics, minimum 30 data is usually required (O'Leary, 2004). When the raw daily precipitation and temperature data were analyzed over North Cyprus, 20 precipitation gauge stations with a continuous length of 33-years (1978-2011/ September - August water year) and 8 temperature gauge stations with a continuous length of 34-years (1978-2011) have been selected. In the second factor, the attention has been given to the distribution of the location of those stations. North Cyprus is divided into six different regions, North Coast and Kyrenia Mountains, West Mesaoria Plain, Middle Mesaoria Plain, East Mesaoria Plain, East Coast, and Karpass Peninsula regions. The detail information about stations is given in Table A.1 (Appendix A). Since the selected stations are distributed uniformly across North Cyprus as seen in Figure 4.1 and Figure 4.4, it is assumed that they represent the climatic characteristics of North Cyprus.

4.1 Precipitation Data

The meteorological data records that were used in this study consist of 20 precipitation gauge stations across North Cyprus. The information about precipitation data is given in Table 4.1. Except two stations (Akdeniz and Yeşilırmak), all 18 stations have continuous 33 years of data ranging from 1978 to 2011. Akdeniz station has 3 years missing values in 1995, 1996, and 1997. Yeşilırmak station has missing values only in 1994 for three months (October, November, and December). These missing values of these two gauge stations were filled in by Inverse Distance Method with using the available data of neighboring stations corresponding to the same period of times (Table 4.3, Figure 4.2 and Figure 4.3).

Table 4.1 Precipitation stations, period of record and missing values

Stations for Rainfall Data	**Period**	**Missing Values**
North Coast and Kyrenia Mountains Region		
Çamlıbel	1978-2011	
Akdeniz	1978-2011	1995,1996, and 1997
Girne	1978-2011	
Alevkayası	1978-2011	
Kantara	1978-2011	
West Mesaoria Plain Region		
Zümrütköy	1978-2011	
Lefke	1978-2011	
Güzelyurt	1978-2011	
Yeşilırmak	1978-2011	1994 (Oct. Nov. and Dec)
Gaziveren	1978-2011	
Middle Mesaoria Plain Region		
Alayköy	1978-2011	
Lefkoşa	1978-2011	
Ercan	1978-2011	
East Mesaoria Plain Region		
Geçitkale	1978-2011	
Dörtyol	1978-2011	
East Coast Region		
Gazi Mağusa	1978-2011	
İskele	1978-2011	
Karpass Peninsula Region		
Mehmetçik	1978-2011	
Yeni Erenköy	1978-2011	
Dipkarpaz	1978-2011	

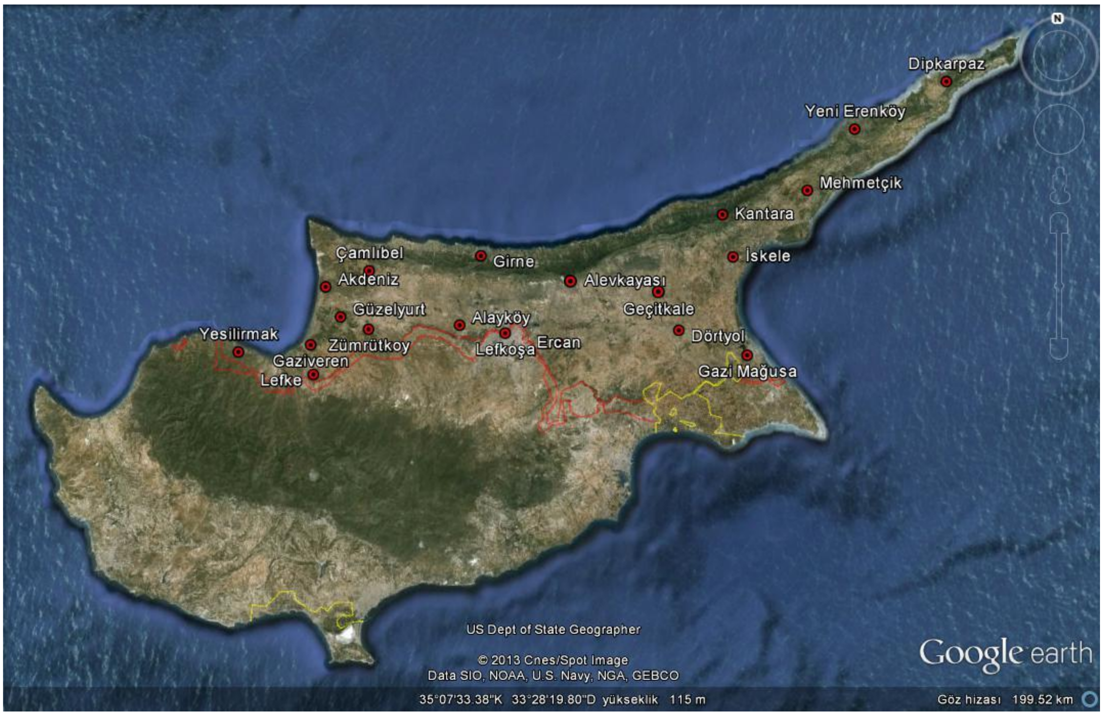

Figure 4.1 Precipitation gauge stations across North Cyprus.

In the trend analysis, the total monthly, seasonal and annual precipitation variables that are extracted from the raw daily data were used. The precipitation variables and their definitions that were used in this project are given in Table 4.2.

Table 4.2 Definitions of the precipitation variables

Acronym	Variable	Explanation	Unit
Ran	Annual rainfall	Annual total rainfall for September-August water year.	mm/ year
Rse	Seasonal rainfall	Seasonal total rainfall for each season in the September-August water year.	mm/ season
Rmo	Monthly rainfall	Monthly total rainfall for each month in the September-August water year.	mm/ month

Table 4.3 Missing data stations, reference stations, and distance between these stations

Missing Data Station	Reference Stations	Distance to Missing Data Station (km)
Yeşilırmak	Lefke	12.1
	Yeşilyurt	13.3
	Gaziveren	16.1
Akdeniz	Çamlıbel	10.3
	Kozanköy	16.1
	Güzelyurt	12.0

Lefke, Gaziveren, Çamlıbel and Güzelyurt neighboring reference stations have continuous 33 years of data and they were used also in trend analysis in addition to their usage in filling missing data. However, Yeşilyurt and Kozanköy stations have short data but corresponding to the same period of desired times. Therefore, they were selected to be used in Inverse Distance Method.

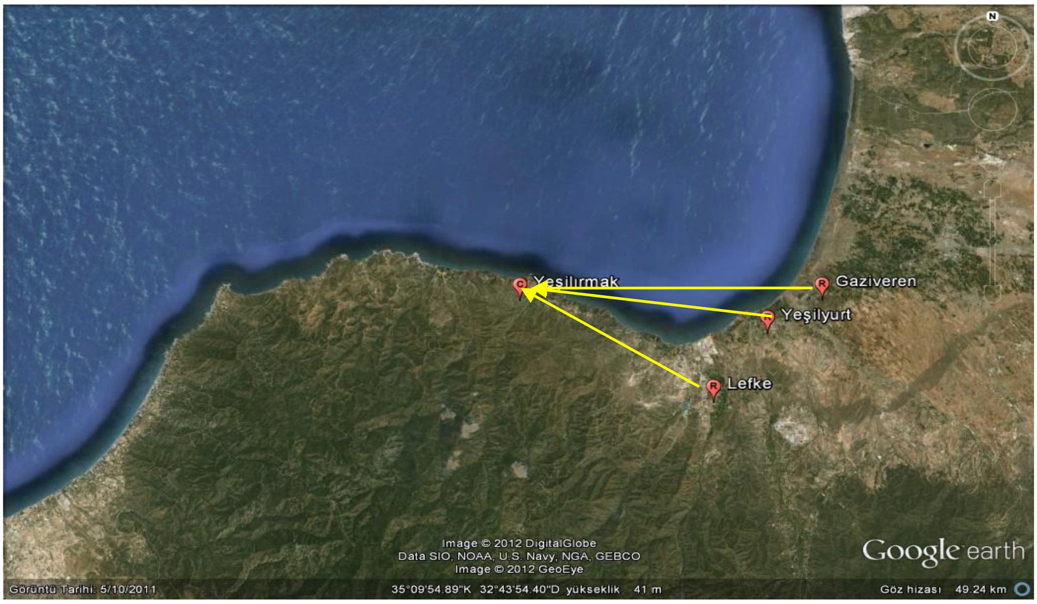

Figure 4.2 Missing data station (Yeşilırmak) and reference stations (Gaziveren, Yesilyurt and Lefke)

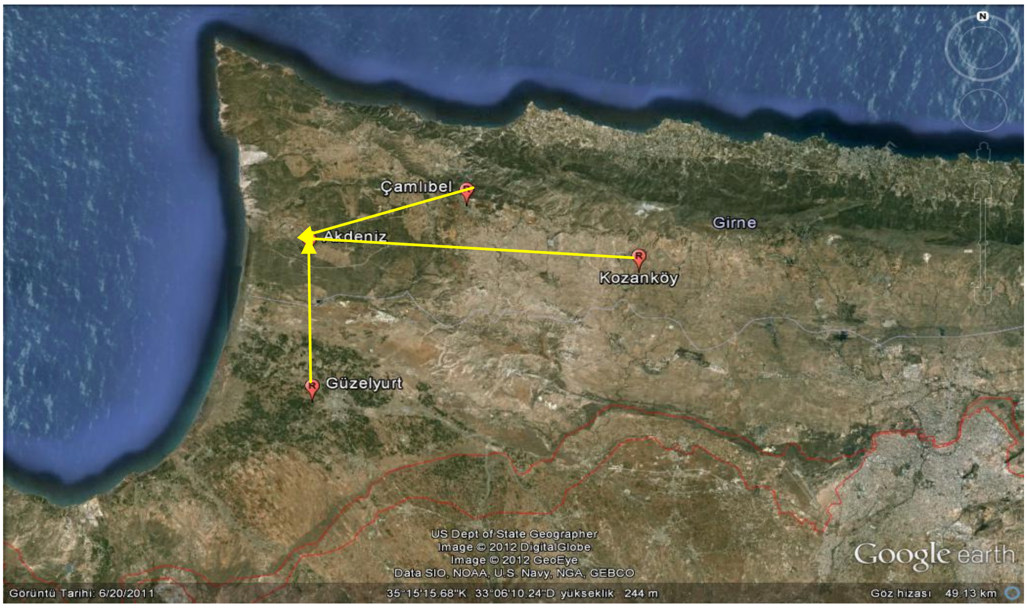

Figure 4.3 Missing data station (Akdeniz) and reference stations (Çamlıbel, Güzelyurt and Kozankoy)

4.2 Temperature Data

The meteorological data records that were used in this study consist of 8 temperature stations across North Cyprus. Although there are few missing parts in the temperature data, all 8 stations have continuous 34/33 years of data ranging from 1978/1979 to 2011 (Table 4.4). These missing parts are filled in by Inverse Distance Method with using the available data of neighboring stations corresponding to the same period of times (Table 4.5).

In the trend analysis, the average monthly maximum and minimum temperatures are derived from the average of the daily maximum and minimum temperatures. The average monthly average temperatures are obtained from the average of the daily average temperatures. In addition to this, the monthly average diurnal temperature is obtained by taking the difference between the average monthly maximum and minimum temperatures. These values, except diurnal temperatures, were obtained directly from North Cyprus Meteorological Office. The temperature variables and their definitions that were used in this study are given in Table 4.6.

Table 4.4 Temperature stations, period of record and missing values

Stations for Temperature Data	**Period**	**Missing Values**
av (Tmax)		
Alevkayasi	1978-2011	
Çamlibel	1978-2011	
Ercan	1978-2011	
Gazi Mağusa	1978-2011	
Girne	1978-2011	
Güzelyurt	1978-2011	
Lefkoşa	1978-2011	
YeniErenköy	1978-2011	
max (Tmax)		
Alevkayası	1978-2011	
Çamlıbel	1979-2011	1996 (Sep.)
Ercan	1978-2011	
Gazi Mağusa	1978-2011	
Girne	1978-2011	
Güzelyurt	1979-2011	
Lefkoşa	1978-2011	
YeniErenköy	1978-2011	
av (Tmin)		
Alevkayası	1978-2011	
Camlıbel	1978-2011	1996 (Sep)
Ercan	1978-2011	
Gazi Mağusa	1978-2011	
Girne	1978-2011	
Güzelyurt	1978-2011	
Lefkoşa	1978-2011	
YeniErenköy	1978-2011	

Table 4.4 Temperature stations, period of record and missing values (con’t)

min (Tmin)	**Period**	**Missing Values**
Alevkayası	1979-2011	
Camlibel	1979-2011	1985 (Apr.), and 1996 (Sep.)
Ercan	1978-2011	
Gazi Mağusa	1978-2011	1981 (Apr., May, Jun., Jul., Aug., Oct., and Dec.)
Girne	1978-2011	
Güzelyurt	1979-2011	
Lefkoşa	1978-2011	
Yeni Erenköy	1979-2011	1994 (Apr., May, Jun., Jul., Aug., Oct., Nov., and Dec.) 1995 (Nov. and Dec.)
av (Tav)		
Alevkayası	1978-2011	
Çamlıbel	1979-2011	
Ercan	1978-2011	
Gazi Mağusa	1978-2011	
Girne	1978-2011	
Güzelyurt	1978-2011	
Lefkoşa	1978-2011	
Yeni Erenköy	1978-2011	
Tdiurnal		
Alevkayası	1978-2011	
Çamlıbel	1978-2011	av(Tmin) ➔ 1996 (Sep.)
Ercan	1978-2011	
Gazi Mağusa	1978-2011	
Girne	1978-2011	
Güzelyurt	1978-2011	
Lefkoşa	1978-2011	
Yeni Erenköy	1978-2011	

Table 4.5 Missing data stations, reference stations, and distance between these stations.

Missing Data Station	**Reference Stations**	**Distance to Missing Data Station (km)**
Çamlıbel	Güzelyurt	14.99
	Girne	24.48
Gazi Mağusa	Alevkayası	40.75
	YeniErenkoy	49.77
	Ercan	36.47
YeniErenkoy	Gazi Mağusa	49.43
	Alevkayası	63.36

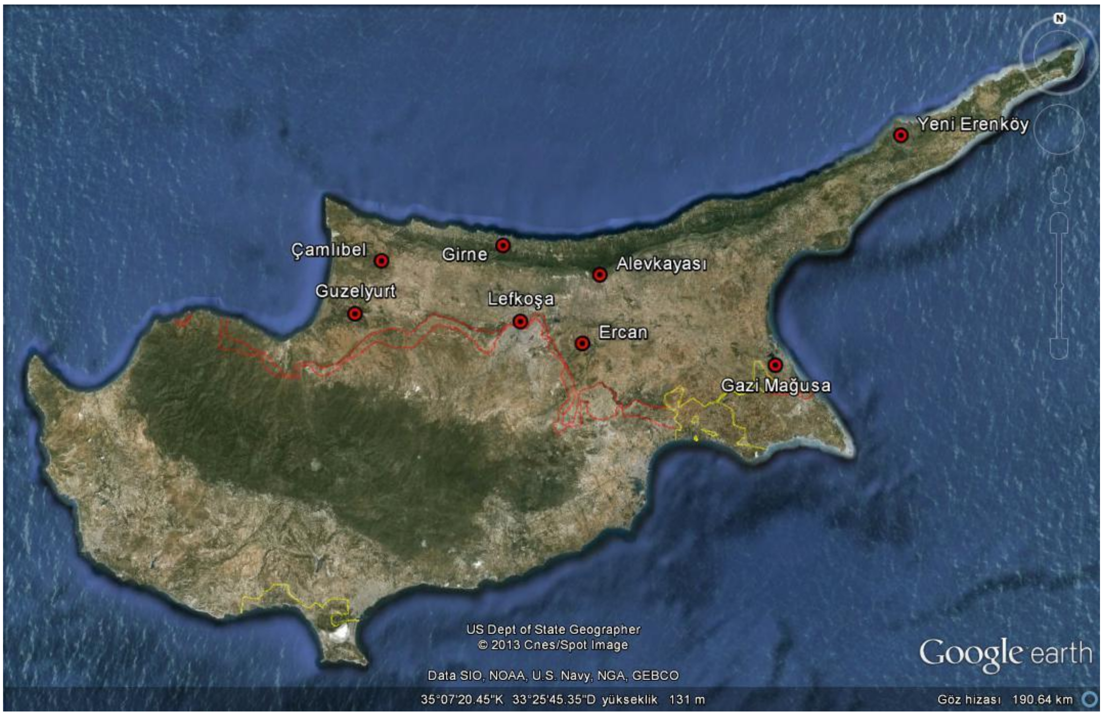

Figure 4.4 Selected temperature gauge stations across North Cyprus

Table 4.6 Definitions of the temperature variables

Acronym	Explanation	Unit
av(Tmax)	Average of monthly maximum temperature	°C
max(Tmax)	Maximum of monthly maximum temperature	°C
av(Tmin)	Average of monthly minimum temperature	°C
min(Tmin)	Minimum of monthly minimum temperature	°C
av(Tav)	Average of monthly average temperature	°C
DTR	Monthly diurnal temperature ranges [av(Tmax) – av(Tmin)]	°C

4.3 Conclusion for Meteorological Data

Distribution of the location of selected temperature and precipitation stations is important. The stations in this study are distributed uniformly, and it is assumed that these selected stations reflect the regional hydroclimatic conditions of North Cyprus. Data for both precipitation and temperature variables is from 1978 to 2011. 34 years data was used for trend detection in temperature variables, while 33 September - August water years data was used for analysis in precipitation variables. Because the rain season starts in September, September-August water year was used for the analysis of precipitation variables.

The rainfall data was obtained as a raw daily data from the meteorological office of North Cyprus, and then converted to the total monthly, seasonal, and annual precipitation variables. It is important to make study with annual rainfall variable, because it gives information about the changes in total rainfall amount in North Cyprus. Since the changes in seasonal and monthly variables affect agricultural industry and water resources management in North Cyprus, seasonal and monthly variables were also analyzed in this study.

Six different temperature variables were studied which are av(Tmax), max(Tmax), av(Tmin), min(Tmin), av(Tav) and DTR (see Table 4.6). These variables except DTR were directly obtained from the Meteorological Office of North Cyprus. DTR obtained by taking the difference between the average monthly maximum and minimum temperatures. It is important to study av(Tav) variable, because it gives information about the changes in average temperatures. To be able to have idea about nighttime changes in temperatures av(Tmin) and min(Tmin) variables were studied. In addition, av(Tmax) and max(Tmax) variables were studied to learn if there is any changes in daytime temperatures. Analysis about diurnal temperature range is also important to learn if there is any significant changes in the differences between nighttime and daytime temperatures.

CHAPTER V

RESULTS AND DISCUSSIONS

The computer code of Mann-Kendall, Seasonal Kendall, Sen’s T, and Seasonal Sen’s T trend tests given above were developed in MATLAB environment to test if there is trend in given meteorological time series. In the trend analyses, the confidence interval of 90% has been selected. The comparison between the results of Sen’s T / Seasonal Sen’s T and Mann-Kendall / Seasonal Kendall tests was performed. If the trend results of both Sen’s T / Seasonal Sen’s T and Mann-Kendall / Seasonal Kendall tests show that there is a trend, the trend is accepted. In this study, the results of the Sen’s T / Seasonal Sen’s T test seemed to be fairly similar to those obtained from the Mann-Kendall / Seasonal Kendall test, which can be seen from Table 5.1 to Table 5.10.

5.1 Trends in Annual and Monthly Precipitation

The results of annual and monthly precipitation trend analyses are given in Table 5.1. The results show that there is no significant trend in the annual rainfall time series almost in all stations. According to the trend analysis results of each month, in most of the stations, significant upward trends in September and downward trends in March rainfall have been observed. The distribution of September and March trends are given in Figure 5.1 and Figure 5.2.

During summer, Cyprus is taking very low or no rainfall. The average July and August rainfall in North Cyprus is 1.5 and 1.8 mm, respectively. Usually the rainfall season starts in September. According to trend test results, one can say that there is an increase in September rainfall while there is a decrease in March rainfall across North Cyprus.

In addition to the trends in September and March, increasing significant trends in different months in only one station have been observed. For example, an increasing trend in January rainfall is observed only in Ercan station, in April rainfall only in Lefke station, in July rainfall only in Alevkayası station, and in August only in Ercan station. A decreasing trend in June rainfall is observed in Güzelyurt and

Gaziveren stations only. On the other hand, there is no any significant trend in November, October, December, and February rainfall in all stations.

Table 5.1 Trend analysis results in annual and monthly total precipitations of North Cyprus.

Station	**Sen's T Test**												
North Coast and Kyrenia Mountains Region	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Annual**
Çamlıbel	—	—	—	—	—	—	—	↑	—	—	↑	—	↑
Akdeniz	↑	—	—	—	—	—	—	—	—	—	—	—	—
Girne	—	—	—	—	—	—	↓	—	—	—	—	—	—
Alevkayası	—	—	—	—	—	—	↓	—	—	—	↑	—	—
Kantara	—	—	—	—	—	—	—	—	—	—	—	—	—
	Mann-Kendall Test												
North Coast and Kyrenia Mountains Region	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Annual**
Camlıbel	—	—	—	—	—	—	—	—	—	—	—	—	—
Akdeniz	—	—	—	—	—	—	—	—	—	—	—	—	—
Girne	—	—	—	—	—	—	↓	—	↑	—	—	—	—
Alevkayası	—	—	—	—	—	—	↓	—	—	—	↑	↑	—
Kantara	—	—	—	—	—	—	↓	—	—	—	—	—	—

Station	**Sen's T Test**												
West Mesaoria Plain Region	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Annual**
Zümrutköy	↑	—	—	—	—	—	—	—	↑	—	—	—	—
Lefke	—	—	—	—	—	—	—	↑	—	—	—	—	↑
Güzelyurt	↑	—	—	—	—	—	—	—	—	↓	—	—	—
Yeşilırmak	—	—	—	—	—	—	—	—	—	—	—	—	—
Gaziveren	↑	—	—	—	—	—	↓	—	—	↓	—	—	—
	Mann-Kendall Test												
West Mesaoria Plain Region	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Annual**
Zümrütköy	↑	—	—	—	—	—	—	—	↑	—	—	—	—
Lefke	—	—	—	—	—	—	—	↑	—	—	—	—	—
Güzelyurt	↑	—	—	—	—	—	—	—	—	↓	—	—	—
Yeşilırmak	—	—	—	—	—	—	—	—	—	—	—	—	—
Gaziveren	↑	—	—	—	—	—	↓	—	—	↓	—	—	—

Table 5.1 Trend analysis results in annual and monthly total precipitations of North Cyprus (con’t)

Station	Sen's T Test											
Middle Mesaoria Plain Region	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Annual**
Alayköy	↑	—	—	—	—	—	↓	—	—	—	—	—	—
Lefkoşa	↑	—	—	—	—	—	—	—	—	—	↑	—	—
Ercan	—	—	—	—	↑	—	↓	—	—	—	—	↑	—
	Mann-Kendall Test												
Middle Mesaoria Plain Region	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Annual**
Alayköy	↑	—	—	—	—	—	↓	—	—	—	—	—	—
Lefkoşa	↑	—	—	—	—	—	↓	—	—	—	—	—	—
Ercan	—	—	—	—	↑	—	↓	—	—	—	—	↑	—

Station	Sen's T Test											
East Mesaoria Plain Region	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Annual**
Geçitkale	↑	—	—	—	—	—	↓	—	—	—	—	—	—
Dörtyol	↑	—	—	—	—	—	↓	—	—	—	—	—	—
	Mann-Kendall Test												
East Mesaoria Plain Region	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Annual**
Geçitkale	↑	—	—	—	—	—	↓	—	—	—	—	—	—
Dörtyol	↑	—	—	—	—	—	↓	—	—	—	—	—	—

Table 5.1 Trend analysis results in annual and monthly total precipitations of North Cyprus. (con't)

Station	**Sen's T Test**												
East Coast Region	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Annual**
Gazi Mağusa	↑	—	—	—	—	—	—	—	—	—	—	—	—
İskele	↑	—	—	—	—	—	↓	—	—	—	—	—	—
	Mann-Kendall Test												
East Coast Region	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Annual**
Gazi Mağusa	↑	—	—	—	—	—	—	—	—	—	—	—	—
İskele	↑	—	—	—	—	—	↓	—	—	—	—	—	—

Station	**Sen's T Test**												
Karpass Peninsula Region	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Annual**
Mehmetçik	↑	—	—	—	—	—	—	—	—	—	—	—	—
YeniErenköy	—	—	—	—	—	—	↓	—	—	—	—	—	—
Dipkarpaz	—	—	—	—	—	—	↓	—	—	—	—	—	—
	Mann-Kendall Test												
Karpass Peninsula Region	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Annual**
Mehmetçik	↑	—	—	—	—	—	—	—	—	—	—	—	—
YeniErenkoy	—	—	—	—	—	—	↓	—	—	—	—	—	—
Dipkarpaz	—	—	—	—	—	—	↓	—	—	—	—	—	—

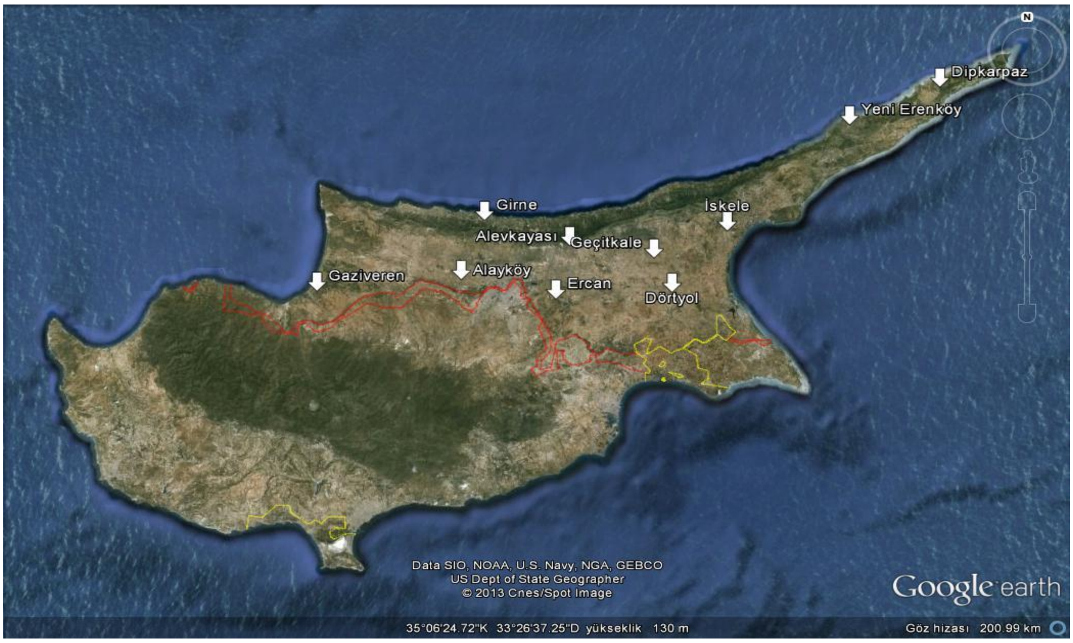

Figure 5.1 Spatial distribution of decreasing trend in March rainfall.

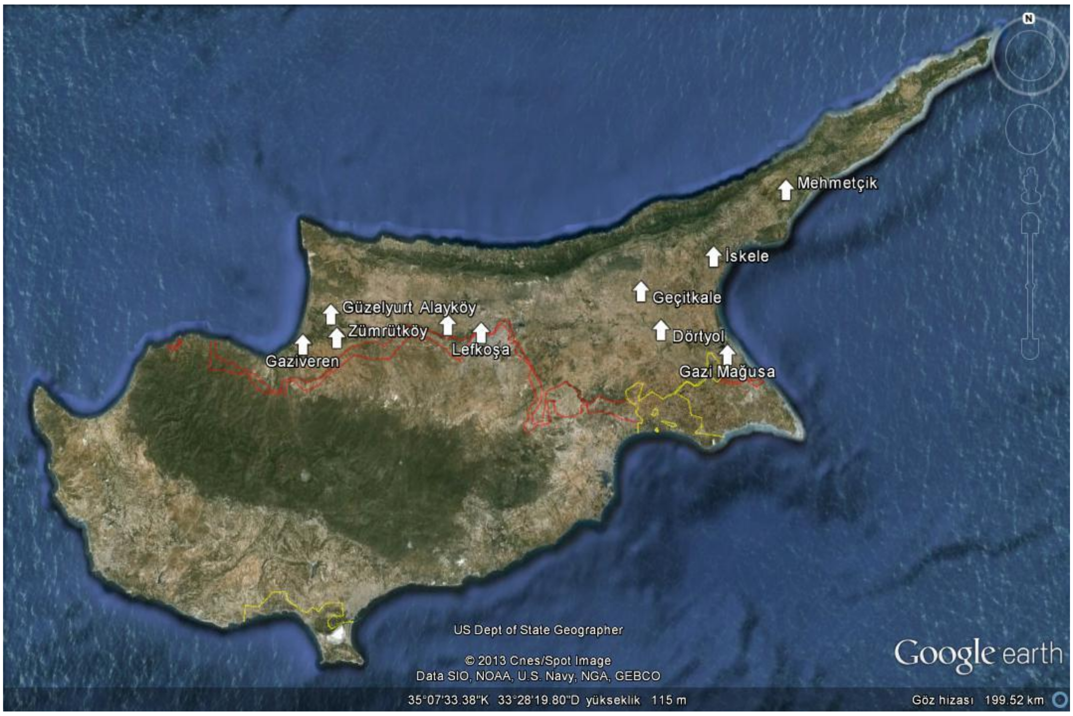

Figure 5.2 Spatial distribution of increasing trend in September rainfall.

As the selected stations are distributed uniformly across North Cyprus, regional interpretation of trend test results is easy to do. In general, significant upward trends in September and downward trends in March rainfall have been observed in most of the stations. However, if we look at the results in a regional basis, we can see that there are differences among six regions. There is no trend in September in the North Coast and Kyrenia Mountains region. In addition to this, there is only one decreasing trend in West Mesaoria Plain region in Gaziveren station, which means about no trend in the region.

5.2. Trends in Seasonal Precipitation

The results showed that there are few significant trends in the seasonal rainfall time series in some of the stations. The results of stations which have trends are given in Table 5.2., while the results for the remaining station and season are given in Appendix B. Although there is one significant downward trend in spring in Yeni Erenköy station, the other downward trends have been observed in summer in Güzelyurt, Gaziveren, and Gazi Magosa stations. In addition, there is only one significant increasing trend which is in fall in Çamlıbel station. As most of the decreasing trends have been observed in summer, it can be concluded that, summer seasons will be far dryer in the future.

Table 5.2 Trend analysis results of precipitation in North Cyprus for each season.

Sen's T Test

Station	**Spring (M,A,M)**	**Summer (J,J,A)**	**Fall (S,O,N)**	**Winter (D,J,F)**
North Coast and Kyrenia Mountains Region				
Çamlıbel	—	—	↑	—
West Mesaoria Plain Region				
Güzelyurt	—	↓	—	—
Gaziveren	—	↓	—	—
East Coast Region				
Gazi Mağusa	—	↓	—	—
Karpass Peninsula Region				
YeniErenköy	↓	—	—	—

Mann-Kendall Test

Station	**Spring (M,A,M)**	**Summer (J,J,A)**	**Fall (S,O,N)**	**Winter (D,J,F)**
North Coast and Kyrenia Mountains Region				
T5yyÇamlıbel	—	—	↑	—
Alevkayası	—	↑	—	—
West Mesaoria Plain Region				
Güzelyurt	—	↓	—	—
Gaziveren	—	↓	—	—
East Coast Region				
Gazi Mağusa	—	↓	—	—
Karpass Peninsula Region				
Yeni Erenköy	↓	—	↓	—

5.3. Trends in Annual and Monthly Temperature

Trend analysis results of different temperature variables that are given in Table 4.6, are presented from Table 5.3 to Table 5.8. The results of monthly, annual and seasonal temperature variables at eight stations are also given in Appendix E and Appendix F with different format.

5.3.1 Changes in the Average of Monthly Average Temperatures

According to the trend test results, the average of monthly average temperatures, av(Tav), show a significant warming trend in summer months in all stations except Çamlıbel station. As seen from Table 5.3, in Girne station which represents the north coast of the island, in Gazi Mağusa station which represents the east coast of the island, and in Yeni Erenköy station which represents the Karpaz Peninsula region, there is an increasing trend almost in all months. In addition to this, there are significant increasing trends in each station, except Çamlıbel station, for annual average of monthly average temperatures. Spatial distribution of increasing trends in annual av(Tav) temperatures is given in the Figure 5.3.

Table 5.3 Trend analysis results of average of monthly average temperature

av(Tav)

Sen's T test

Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annnual**
Yeni Erenköy	↑	—	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Gazi Mağusa	—	—	↑	↑	↑	↑	↑	↑	↑	↑	—	↑	↑
Lefkoşa	—	—	—	—	—	↑	↑	↑	—	—	—	—	↑
Güzelyurt	—	—	—	—	↑	↑	↑	↑	↑	—	—	—	↑
Girne	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Ercan	—	—	—	—	—	↑	↑	↑	—	—	—	—	↑
Çamlıbel	—	—	—	—	—	—	—	—	—	—	—	—	—
Alevkayası	—	—	↑	↑	—	—	↑	↑	↑	—	—	—	↑

Mann-Kendall Test

Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annnual**
Yeni Erenköy	↑	—	↑	↑	↑	↑	—	↑	↑	↑	↑	↑	↑
Gazi Mağusa	—	—	↑	↑	—	↑	↑	↑	↑	↑	—	↑	↑
Lefkosa	—	—	↑	—	—	↑	↑	↑	—	—	—	—	↑
Güzelyurt	—	—	—	—	↑	↑	↑	↑	↑	—	—	—	↑
Girne	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Ercan	—	—	—	—	—	↑	↑	↑	—	—	—	—	↑
Çamlıbel	—	—	—	—	—	—	—	—	—	—	—	—	—
Alevkayası	—	—	—	↑	—	↑	↑	↑	↑	—	—	—	↑

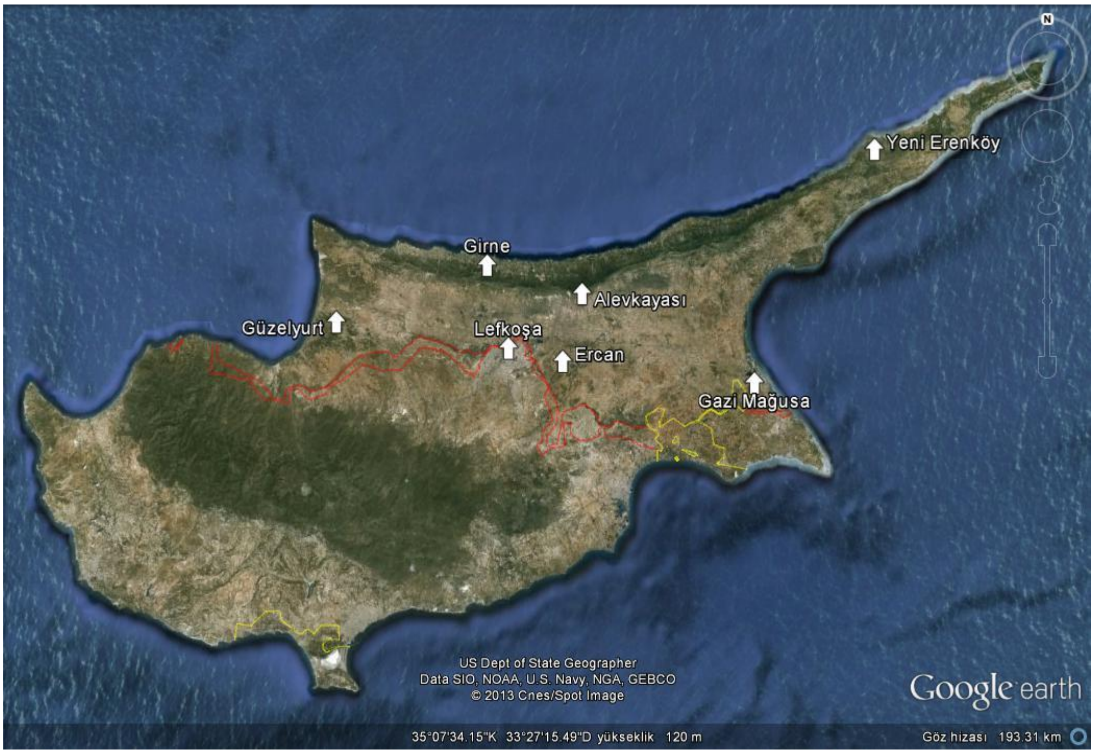

Figure 5.3 Spatial distribution of increasing trends in annual av(Tav) temperatures

5.3.2 Changes in the Average of Monthly Minimum Temperatures

Trend tests are also applied to the average of monthly minimum temperatures. As seen from Table 5.4, except Ercan station, there is a significant warming trend in almost all stations in most of the months. In Ercan, a significant increasing trend is obtained only in August and September average minimum temperatures. There is no trend in the remaining months. When annual average minimum temperature is analyzed, a significant increasing trend in all stations except Ercan is obtained. Spatial distribution of increasing trends in annual av(Tmin) is given in the Figure 5.4.

Table 5.4 Trend analysis results of average of monthly minimum temperature

av(Tmin)

Sen's T test

Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Yeni Erenköy	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Gazi Mağusa	↑	—	↑	↑	↑	↑	↑	↑	↑	↑	—	↑	↑
Lefkoşa	—	—	↑	↑	↑	↑	↑	↑	↑	—	—	—	↑
Güzelyurt	—	—	↑	—	↑	↑	↑	↑	↑	↑	—	—	↑
Girne	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Ercan	—	—	—	—	—	—	—	↑	↑	—	—	—	—
Çamlıbel	—	—	↑	↑	↑	↑	↑	↑	↑	↑	—	—	↑
Alevkayası	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑

Mann-Kendall Test

Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Yeni Erenköy	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Gazi Mağusa	↑	—	↑	↑	↑	↑	↑	↑	↑	↑	—	↑	↑
Lefkoşa	—	—	↑	—	↑	↑	↑	↑	↑	—	—	—	↑
Güzelyurt	—	—	—	—	↑	↑	↑	↑	↑	↑	—	—	↑
Girne	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Ercan	—	—	—	—	—	—	—	↑	↑	—	—	—	—
Çamlıbel	—	—	↑	—	↑	↑	↑	↑	↑	—	—	—	↑
Alevkayası	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑

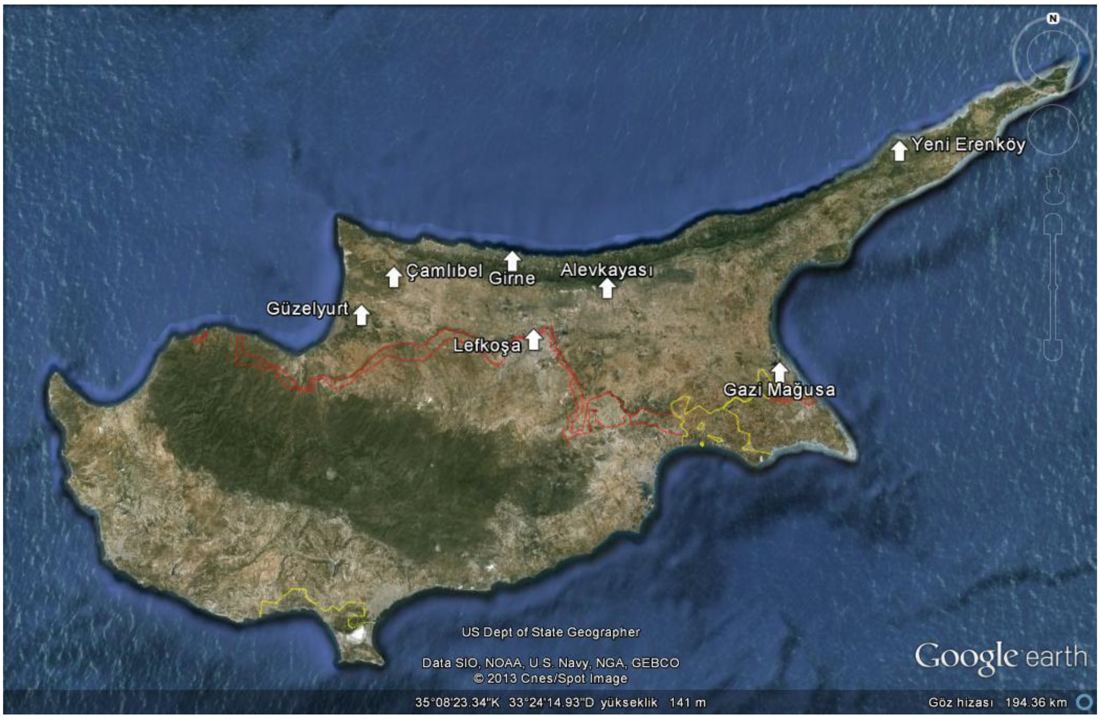

Figure 5.4 Spatial distribution of increasing trends in annual av(Tmin)

5.3.3 Changes in the Minimum of Monthly Minimum Temperatures

When we look at more extreme temperature variables such as minimum of monthly minimum temperatures, min(Tmin), again we can see the increasing trends in all stations during summer months and increasing trends in all months of Yeni Erenköy and Girne stations (see Table 5.5). In Ercan station only one significant increasing trend has been observed during summer which is in August. When annual minimum of monthly minimum temperatures are analyzed, a significant warming trend has been observed in Yeni Erenköy, Güzelyurt, Girne, and Alevkayası stations, and no trend in remaining. Spatial distribution of increasing trends of min(Tmin) in August is given in the Figure 5.5.

Table 5.5 Trend analysis results of minimum of monthly minimum temperature

min(Tmin)

Sen's T test

Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Yeni Erenköy	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Gazi Mağusa	—	—	↑	↑	↑	↑	↑	↑	↑	—	—	↑	—
Lefkoşa	—	—	—	—	—	↑	↑	↑	—	—	—	—	—
Güzelyurt	—	—	↑	—	↑	↑	↑	↑	↑	—	—	—	↑
Girne	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Ercan	—	—	—	—	—	—	—	↑	—	—	—	—	—
Çamlıbel	—	—	↑	↑	↑	↑	↑	↑	↑	—	—	—	—
Alevkayası	—	—	↑	↑	↑	↑	↑	↑	↑	—	↑	—	↑

Mann-Kendall Test

Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Yeni Erenköy	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Gazi Mağusa	—	—	↑	↑	↑	↑	↑	↑	↑	—	—	↑	—
Lefkoşa	—	—	—	—	—	↑	↑	↑	—	—	—	—	—
Güzelyurt	↑	—	↑	—	↑	↑	↑	↑	↑	—	—	↑	↑
Girne	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Ercan	—	—	—	—	—	—	—	↑	—	—	—	—	—
Camlıbel	—	—	—	↑	↑	↑	↑	↑	↑	—	—	—	—
Alevkayası	—	—	↑	↑	↑	↑	↑	↑	↑	—	↑	—	↑

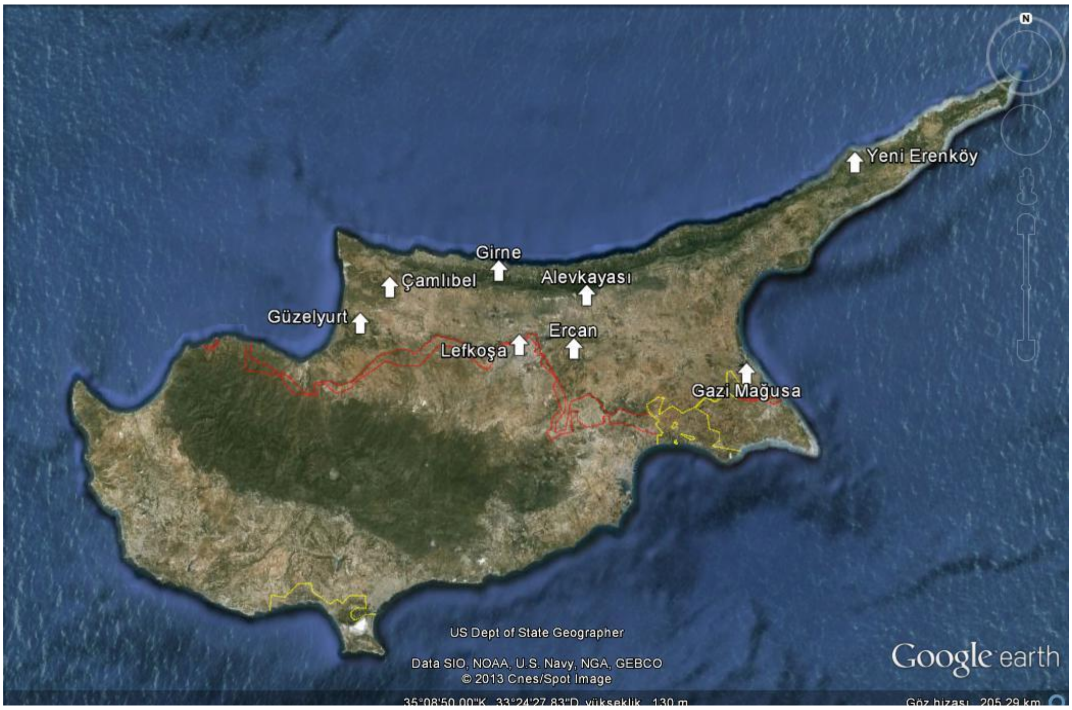

Figure 5.5 Spatial distribution of increasing trends in min(Tmin) in August

5.3.4 Changes in the Average of Monthly Maximum Temperatures

In the trend analysis of temperature variables, monthly average of monthly maximum temperatures, av(Tmax), is also considered. As seen from Table 5.6, there is no trend in two stations namely Çamlıbel and Alevkayası. Both of these stations are located at higher elevations relative to other stations. The results also reveal that all of the trends are increasing trend, and most of them are in March and summer months. Although there are significant warming trends in majority of the stations in annual maximum temperatures, there are no significant trends in Çamlıbel and Alevkayası stations. Spatial distribution of increasing trends in annual av(Tmax) is given in the Figure 5.6.

Table 5.6 Trend analysis results of average of monthly maximum temperature

av(Tmax)

Sen's T test

Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Yeni Erenköy	—	—	↑	—	—	↑	—	↑	↑	—	—	—	↑
Gazi Mağusa	—	—	↑	—	—	—	↑	↑	—	—	—	—	↑
Lefkoşa	—	—	↑	↑	—	↑	↑	↑	—	—	↑	↑	↑
Güzelyurt	—	—	—	—	—	—	↑	↑	—	—	—	—	↑
Girne	—	—	↑	↑	—	—	—	↑	—	—	↑	↑	↑
Ercan	—	—	↑	—	—	↑	↑	↑	—	—	—	—	↑
Çamlıbel	—	—	—	—	—	—	—	—	—	—	—	—	—
Alevkayası	—	—	—	—	—	—	—	—	—	—	—	—	—

Mann-Kendall Test

Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Yeni Erenköy	—	—	↑	↑	—	↑	↑	↑	—	—	↑	↑	↑
Gazi Mağusa	—	—	↑	—	—	↑	↑	↑	—	—	—	—	↑
Lefkoşa	—	—	↑	↑	—	↑	↑	↑	—	—	↑	↑	↑
Güzelyurt	—	—	—	—	—	—	↑	↑	—	—	—	—	↑
Girne	—	—	↑	↑	—	—	—	↑	↑	—	↑	—	↑
Ercan	—	—	↑	—	—	↑	↑	↑	—	—	—	—	↑
Çamlıbel	—	—	—	—	—	—	—	—	—	—	—	—	—
Alevkayası	—	—	—	—	—	—	—	—	—	—	—	—	—

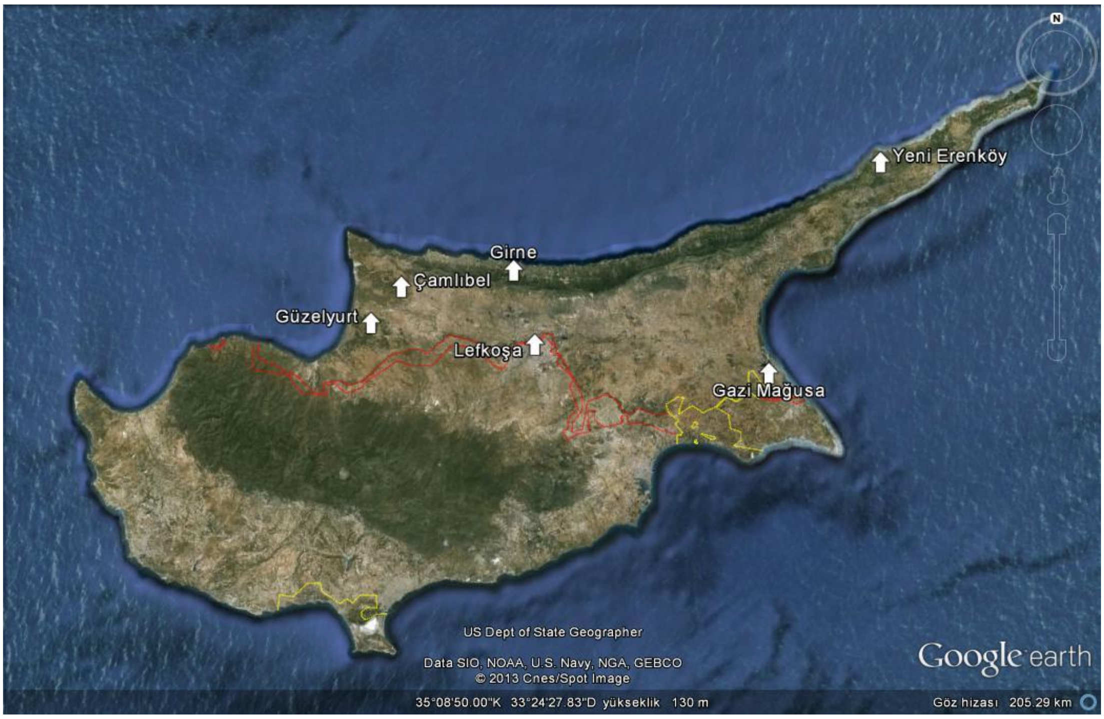

Figure 5.6 Spatial distribution of increasing trends in annual av(Tmax)

5.3.5 Changes in the Maximum of Monthly Maximum Temperatures

On the other hand, when the results of maximum of monthly maximum temperatures are analyzed (Table 5.7), in most of the months, no significant trends are obtained. Majorities of the significant trends are warming trend, and these increasing trends are observed mostly in August in Yeni Erenköy, Lefkoşa, Güzelyurt and Ercan stations. In addition to this, significant warming trends have also been observed in January, February, September, and December in Ercan, Lefkoşa, Alevkayası, and Girne stations, respectively. On the other hand, a decreasing trend in July has been observed in Çamlıbel. When annual max(Tmax) temperatures are analyzed, only one trend, which is a significant upward trend, has been observed in Yeni Erenköy station. The most striking characteristic of these trends is that most of them have been observed in summer especially in August as a warming trend. Spatial distribution of increasing trends in max(Tmax) temperatures in August is given in the Figure 5.7.

Table 5.7 Trend analysis results of maximum of monthly maximum temperature

max(Tmax)													
	Sen's T test												
Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Yeni Erenköy	—	—	—	—	—	—	—	↑	—	—	—	—	↑
Gazi Magosa	—	—	—	—	—	—	—	—	—	—	—	—	—
Lefkoşa	—	↑	—	—	—	—	—	↑	—	—	—	—	—
Güzelyurt	—	—	—	—	—	—	—	↑	—	—	—	—	—
Girne	—	—	—	—	↓	—	—	—	—	—	—	↑	—
Ercan	↑	—	—	—	—	—	—	↑	—	—	—	—	—
Çamlıbel	—	—	—	—	—	—	↓	—	—	—	—	—	—
Alevkayası	—	—	—	—	—	—	—	—	↑	—	—	—	—
	Mann-Kendall Test												
Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Yeni Erenköy	—	—	—	—	—	—	—	↑	—	—	—	—	↑
Gazi Magosa	—	—	—	—	—	—	—	—	—	—	—	—	—
Lefkosa	—	↑	—	—	—	—	—	↑	—	—	—	—	—
Güzelyurt	—	↑	—	—	—	—	—	↑	—	—	—	—	—
Girne	—	—	—	—	—	—	—	—	—	—	—	↑	—
Ercan	—	—	—	—	—	—	—	↑	—	—	—	—	—
Çamlıbel	—	—	—	—	—	—	↓	—	—	—	—	—	—
Alevkayası	—	—	—	—	—	—	—	—	—	—	—	—	—

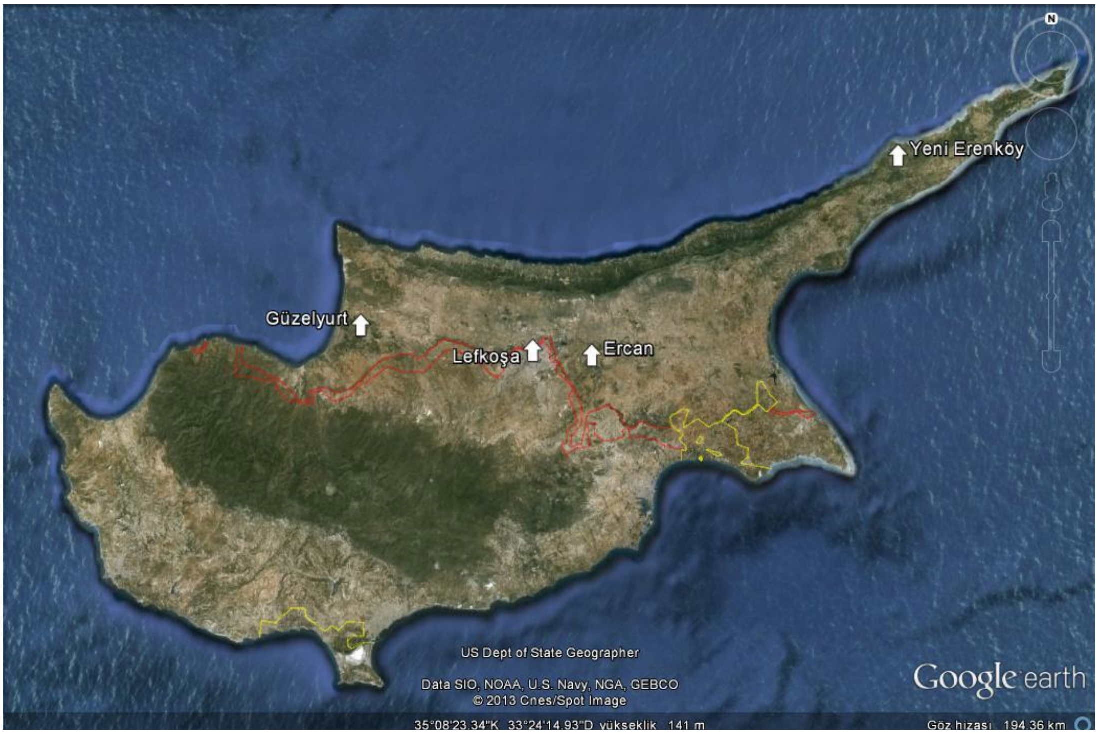

Figure 5.7 Spatial distribution of increasing trends in max(Tmax) temperatures in August

5.3.4 Changes in the Diurnal Temperature Ranges (DTR)

Looking at the trends in diurnal temperature ranges is also a common application. When annual DTR is analyzed, significant decreasing trend in all months is seen in Yeni Erenköy, Girne, and Alevkayası stations. Moreover, significant downward trends have been also observed from April to October, from April to September and from August to October in Gazi Mağusa, Çamlıbel and Güzelyurt stations, respectively. On the other hand, significant upward trends have been observed in March, July, and November in Ercan station, while there is no any trend in Lefkoşa station (see Table 5.8). Spatial distribution of downward trends of annual DTR temperatures is given in the Figure 5.8.

Table 5.8 Trend analysis results of monthly diurnal temperature

DTR

Sen's T test

Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Yeni Erenköy	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
Gazi Mağusa	—	—	—	↓	↓	↓	↓	↓	↓	↓	—	—	—
Lefkoşa	—	—	—	—	—	—	—	—	—	—	—	—	—
Güzelyurt	—	—	—	—	—	—	—	↓	↓	↓	—	—	↓
Girne	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
Ercan	—	—	↑	—	—	—	↑	—	—	—	↑	—	↑
Camlıbel	—	—	—	↓	↓	↓	↓	↓	↓	—	—	—	—
Alevkayası	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓

Mann-Kendall Test

Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Yeni Erenköy	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
Magosa	—	—	—	↓	↓	↓	↓	↓	↓	↓	—	—	—
Lefkoşa	—	—	—	—	—	↓	—	—	—	—	—	—	—
Güzelyurt	—	—	—	—	—	—	—	↓	↓	↓	—	—	↓
Girne	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
Ercan	—	—	↑	—	—	—	↑	—	—	—	↑	—	↑
Camlıbel	—	—	—	↓	↓	↓	↓	↓	↓	—	—	—	—
Alevkayası	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓

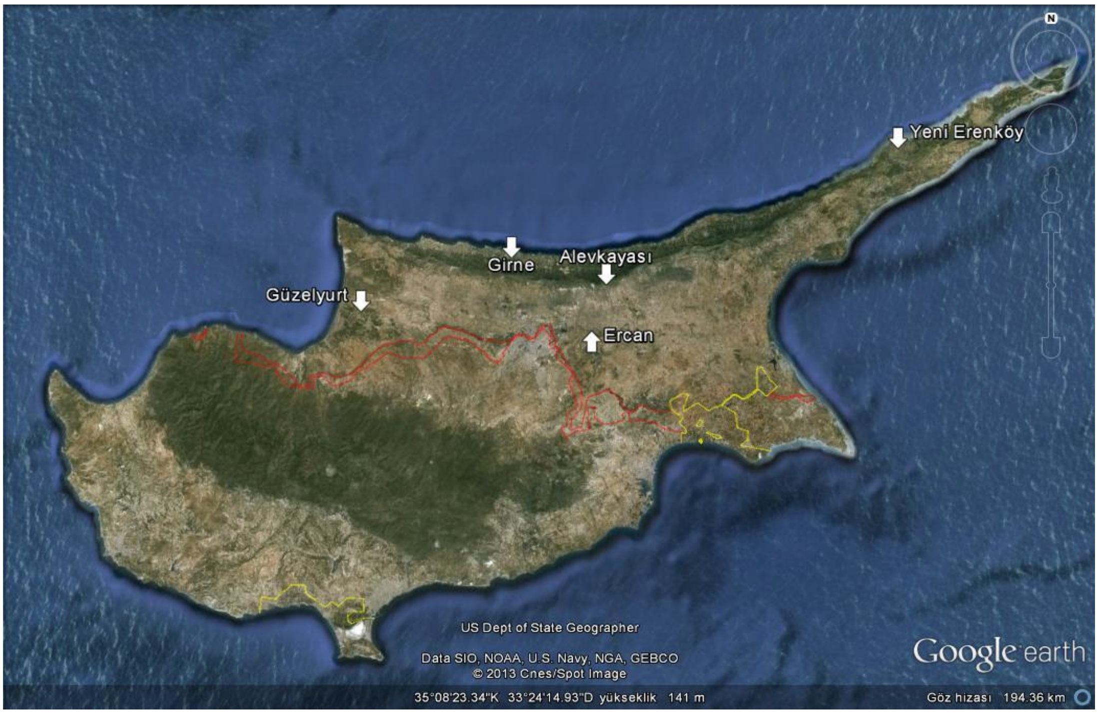

Figure 5.8 Spatial distributions of trends of annual DTR

According to the results of average of monthly maximum (daytime maximum) and minimum (nighttime minimum) temperature trend analyses, differential behavior between day and night has been evaluated (DTR). The average maximum and minimum temperatures have both increased during the period, although the minimum temperatures have increased at a faster rate (Appendix C and D). Therefore, most of the stations, except Ercan and Lefkosa stations, show significant decreases in monthly diurnal temperature range.

Stations showed different climatic conditions due to the locations of them (coastal, inland, and high elevation station). Lefkoşa and Ercan stations are located inland, away from the coastline, while the Yeni Erenkoy, Magosa and Girne stations are coastal stations. Çamlıbel and Alevkayası are the high elevation stations at elevation of 277 m and 623 m, respectively. According to these locations, it can be said that the average minimum temperatures has increased at a faster rate in the coastal and high elevation stations in comparison with inland stations. Therefore, the number of months with decreasing trend in diurnal temperature range is bigger in coastal and high elevation stations than inland stations.

There are two main possible causes of the changes in the diurnal temperature range which are increased urbanization of Cyprus, resulting in a heat island effect during nighttime hours relative to daytime hours and regional or global climate change, resulting from more aerosols and cloud cover (Price et al., 1999). Air and surface temperatures in intensely built urban and suburban areas are higher than the temperatures of the surrounding rural areas. The phenomenon is known as 'heat island'. The reason for this is the many common constructions in urban and suburban areas which absorb and retain the sun's heat more than the natural materials in rural areas. In addition to this, human-produced heat (anthropogenic heat), slower wind speeds and air pollution in urban areas also effective in the formation of heat island (Price et al., 1999 and Gartland, 2008). Heat islands have huge effects on the communities with summertime peak energy demand, air conditioning costs, air pollution, heat related illness and mortality, and likewise.

The heat island effect is larger in the summer months (June, July and August) than in the winter months (December, January and February) (Price et al., 1999). If we look at the trends for both of the seasons for North Cyprus, we can clearly say that the trends in minimum and maximum temperatures, which are increasing trends, are stronger in summer than in winter. Because of that, the number of decreasing trends in monthly diurnal temperatures in summer time is more than in winter season. But the heat island effect can only explain small piece of the decreasing trend in DTR temperature. The effects of regional and global climate change should also be examined. Unfortunately, aerosols and cloud cover data are not available for these stations. Therefore, it was not possible to check the validity of the hypothesis of regional or global climate change. In brief, further investigations should be done to be able to say that the reason of the trends is truly regional or global climate change, or local effects such as urbanization.

5.4 Trends in Seasonal Precipitation and Temperature

In the trend analysis of seasonal precipitation and temperature variables, seasonal Mann-Kendall and seasonal Sen'sT tests were used. The results are given in Table 5.9 and Table 5.10 for precipitation and temperature variables, respectively. Spatial distributions of trends of precipitation and temperature trends are given in Appendix G.

5.4.1 Trends in Seasonal Precipitation

As seen from Table 5.9, there are upward trends in only two stations, Lefke and Çamlıbel, in the seasonal precipitation time series, which means that there is not a big change during the period in the rainfall regime of North Cyprus.

Table 5.9 Trend analysis results in seasonal precipitations of North Cyprus.

Precipitation	**Güzelyurt**	**Zümrutköy**	**Yeşilırmak**	**Mehmetçik**	**Gazi Mağusa**	**Lefkoşa**	**Lefke**	**Dipkarpaz**	**Kantara**	**İskele**
Seasonal Sen's T Test	—	—	—	—	—	—	↑	—	—	—
Seasonal Mann-Kendall Test	—	—	—	—	—	—	↑	—	—	—

Precipitation	**Girne**	**Geçitkale**	**Gaziveren**	**Yeni Erenköy**	**Ercan**	**Dörtyol**	**Çamlıbel**	**Alevkayası**	**Alayköy**	**Akdeniz**
Seasonal Sen's T Test	—	—	—	—	—	—	↑	—	—	—
Seasonal Mann-Kendall Test	—	—	—	—	—	—	↑	—	—	—

5.4.1 Trends in Seasonal Temperature

There are many strong trends in temperature variables which are given in Table 5.10. Significant warming trends in all variables except diurnal temperature range have been observed. According to the stronger increases in the minimum temperature than maximum temperature, decreasing trends have been observed in the diurnal temperature ranges.

Table 5.10 Trend analysis results in seasonal temperature of North Cyprus.

Temperature	**YeniErenköy**	**Gazi Magosa**	**Lefkoşa**	**Guüzelyurt**	**Girne**	**Ercan**	**Çamlıbel**	**Alevkayası**
av(Tav)								
Seasonal Sen's T Test	↑	↑	↑	↑	↑	↑	↑	↑
Seasonal Mann-Kendall Test	↑	↑	↑	↑	↑	↑	↑	↑
min(Tmin)								
Seasonal Sen's T Test	↑	↑	↑	↑	↑	—	↑	↑
Seasonal Mann-Kendall Test	↑	↑	↑	↑	↑	—	↑	↑
av(Tmin)								
Seasonal Sen's T Test	↑	↑	↑	↑	↑	↑	↑	↑
Seasonal Mann-Kendall Test	↑	↑	↑	↑	↑	↑	↑	↑
max(Tmax)								
Seasonal Sen's T Test	↑	—	↑	↑	—	↑	—	—
Seasonal Mann-Kendall Test	↑	—	↑	↑	—	↑	—	—
av(Tmax)								
Seasonal Sen's T Test	↑	↑	↑	↑	↑	↑	—	—
Seasonal Mann-Kendall Test	↑	↑	↑	↑	↑	↑	—	—
DTR								
Seasonal Sen's T Test	↓	↓	—	↓	↓	↑	↓	↓
Seasonal Mann-Kendall Test	↓	↓	—	↓	↓	↑	↓	↓

5.5 Comparison of the Results with the Trends Test Results of South Cyprus and Mediterranean Region of Turkey

The study of Partal and Kahya (2002) shows the trend test results of precipitation in Turkey. In this study, Mann-Kendall and Sen’s T tests were used for the 1929-1993 study period. The results show that there are decreasing trends in September and one increasing trend in March in the Mediterranean region. In addition to this, the trend for annual total precipitation is increasing in the region. An increasing trend in September, decreasing trend in March, and no trend in annual total precipitation have been observed in North Cyprus. Therefore, the results for North Cyprus are not similar with the results for Mediterranean region of Turkey. Although the same trend analysis methods have been employed in both trend studies, it is worth to note that the data periods that are considered are different.

Turkes et al. (1996) examined 59 stations during the period of 1930 - 1993. The aim of the study was to observe changes in temperature variables in Turkey for different regions. Mann-Kendall and Wald-Wolfowitz serial correlation tests were used in this study. The results for Mediterranean region show that maximum temperatures have decreased in all seasons except spring, but none of them were significant. Mean minimum temperatures have increased markedly. In addition to this, diurnal temperature ranges have decreased strongly. Although the results of the study of Turkes et al. (1996) shows similarities with the results of the study here, there are differences in annual maximum temperature indices. Because, it was found that the trends in annual maximum temperature indices increased like trends in annual minimum temperature for both inland and coastal stations in North Cyprus.

Price et al. (1999) examined two stations which are coastal station Limasol (from 1903 to 1996) and inland station Nicosia (from 1896 to 1996). The purpose of this study was to analyze long term changes in diurnal temperature in Cyprus. A linear regression model was used to calculate the correlation coefficients and the rate of change was defined by the slope of the linear regression curves. It was found that the annual maximum temperature indices are decreased slightly at Limasol station, while the annual minimum temperature at this station has increased significantly. In addition to this, maximum and minimum temperatures have both increased at Nicosia station, while the warming trend for minimum temperature is more rapid than maximum temperature. Therefore, dramatic decreases in the annual mean diurnal temperature range have been observed in both stations. Although the results of the study of Price et al., (1999) shows similarities with the results of the study here, there are differences in annual maximum temperature indices. Because it was found that there are increasing trends in annual maximum temperature indices for both inland and coastal stations of North Cyprus.

Although the North Cyprus, South Cyprus, and Turkey are in the Mediterranean region, there are differences among trend test results of them. The reason of this might be the topographic differences.

CHAPTER VI

CONCLUSIONS

Water scarcity is one of the major problems faced by the people of Northern Cyprus, and has been a rising alarming over the past 30 years. During summer, North Cyprus is taking very low or no rainfall. The small amounts that fall are rapidly absorbed by the very dry soil and soon evaporated by high temperatures. Because of that, precipitation during summer months is about nothing for water resources and agriculture, and the amount of rainfall in autumn and winter plays an important role at this point.

Changes in rainfall regime directly affect the water resources management, agricultural system and ecosystem in Cyprus because of the semi-arid climate. It can be said that rainfall is the limiting factor in the crop cultivation in the island, as it affects the crop yields and determine the selection of the crops that can be grown. Trend results of this study for precipitation data show that there are no significant changes in the annual precipitation fall, although there is a shift in monthly rainfall regime as there is an upward trend in September and a downward trend in March rainfall.

On the other hand, it has been observed that there are strong increasing trends in the annual temperature variables except trends in annual diurnal temperature range. While trends in average of monthly minimum temperature (nighttime minimum) have increased at a faster rate according to the increases in the trends of average of monthly maximum (day time maximum) temperatures, trends in diurnal temperature range have decreased. In other words, the nights in summer are getting hotter, which makes people to be more depressed and use more energy to become cooler. As the nights in winter are also getting warmer in Yeni Erenköy, Girne, and Alevkayası stations, it can be said that the number of very cold winter nights decreased. It is also important that, these warming trends in temperature cause great amount of water to evaporate which limits the availability of water for agricultural system.

Trend results in autumn and winter, which play important roles for water resources and agriculture, show that there are strong warming trends in temperature, while there are no significant changes in rainfall. In addition to this, we have confidence that temperatures will continue to rise due to increasing greenhouse gases (IPCC, 2001). Therefore, it seems that the amounts of rainfall will not mask a tendency for rising drought due to increasing temperature, and North Cyprus will continue to fight with water scarcity.

The main water resource in North Cyprus is the groundwater, but some aquifers already have been over-pumped and much of the ground water is over salted (Ministry of Agriculture, North Cyprus). As there has been visible overconsumption of water resources especially for agricultural purposes, the trend analysis results here will guide agricultural industry and water resources management in North Cyprus.

While the population of North Cyprus grows, the needs for water increase in agriculture and households. Water is vital for sustaining life, therefore, it is necessary to supply enough water. In addition to this, standards of water quality must be determined for different types of water usage and they have to be tested periodically by governmental organizations. As the great amount of water in the aquifers is over salted in North Cyprus, wastewater treatment strategies might be developed to clean over salted water and make it ready for safe usage. While it is concluded in this study that North Cyprus will continue to fight with water scarcity, government might set up rules about the usage of water. For instance, the cost of water per gallon can be increased to prevent unnecessary water usage.

It has been documented that increased greenhouse gas concentration in the atmosphere has resulted in the increase of the global average surface temperature (IPCC, 2007). Because of that, the government in North Cyprus should take precautions about the amount of CO_2 emissions. Although Cyprus is not a big island, the number of cars is quite large in the island which causes great amount of exhaust emissions. Therefore, public transportation might be developed and ticket prices might be decreased to make people to select public transportation instead of using their own car for transportation.

Because of the high temperature, most of the people in North Cyprus use air conditioning for cooling which meens that great amount of enery is used to become cooler. Therefore, alternative renewable energy sources such as solar power stations might be deployed. Furthermore, people who want to produce their own energy might be supported by the government.

Upward trends have been observed in each station for temperature variables. On the other hand, *T* values of Sen's T test and *Z* values of Mann-Kendall test for Çamlıbel and Alevkayası stations are not strong as for the other stations in summer. Therefore, moving to the places, like Çamlıbel and Alevkayası, which are located at higher elevations relative to the other places in North Cyprus, can be an alternative solution to the increased temperatures.

In the relevant previous studies, there is a common conclusion about climate change and trend results. It is indicated that, it would not be appropriate to say that the observed trends have occurred as a result of climate change (Kahya and Kalycı, 2004), and further studies are needed. The results in this study are also not enough to be able to say that the reason for changes in temperature and precipitation in North Cyprus is climate change. More extreme variables might be needed to be studied. On the other hand, the results will contribute to the researches about the effects of climate change in the Mediterranean region.

IPCC 2001 suggests that there will be changes in extreme climate events in the future. Therefore, as a further study, the investigation of trend analysis of number of extreme events such as number of days temperature was above 30˚C per year, number of days rainfall is above 20 mm per day per year, and trend analysis of Palmer Drought Severity Index is recommended.

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APPENDICES

APPENDIX A

Table A.1 Station information and data period

Stations	Station no.	Station code	Station model	Latitude	Longitude	Elevation	Period
North Coast and Kyrenia Mountains Region							
Çamlibel	17570	LCCA	Rainfall	35^{0}18'58"	33^{0}04'14"	277	1978-2011
Akdeniz	17505	LCAK	Rainfall	35^{0}17'59"	32^{0}57'54"	89	1978-2011
Girne	17510	LCGR	Rainfall	35^{0}20'31"	33^{0}19'53"	10	1978-2011
Alevkayası	17560	LCAL	Rainfall	35^{0}17'09"	33^{0}32'05"	623	1978-2011
Kantara	17563	LCKA	Rainfall	35^{0}24'02"	33^{0}54'49"	480	1978-2011
West Mesaoria Plain Region							
Zümrütköy	17506	LCZU	Rainfall	35^{0}10'28"	33^{0}02'57"	129	1978-2011
Lefke	17501	LCLF	Rainfall	35^0 46'48"	32^{0}50'59"	129	1978-2011
Güzelyurt	17500	LCGU	Rainfall	35^{0}11'20"	32^{0}58'55"	52	1978-2011
Yeşilırmak	17507	LCYS	Rainfall	35^{0}09'59"	32^{0}44'13"	20	1978-2011
Gaziveren	17504	LCGA	Rainfall	35^{0}10'23"	32^{0}55'19"	19	1978-2011
Middle Mesaoria Plain Region							
Alayköy	17511	LCAY	Rainfall	35^{0}11'05"	33015'24"	166	1978-2011
Lefkoşa	17515	LCLS	Rainfall	35^{0}11'47"	33021'07"	134	1978-2011
Ercan	17521	LCEN	Rainfall	35^{0}09'33"	33030'07"	119	1978-2011
East Mesaoria Plain Region							
Geçitkale	17530	LCGK	Rainfall	35^{0}14'00"	33 43'43"	45	1978-2011
Dörtyol	17534	LCDO	Rainfall	35^{0}10'44"	33045'31"	54	1978-2011
East Coast Region							
Mağusa	17540	LCMG	Rainfall	35^{0}08'11"	33056'08"	0	1978-2011
İskele	17535	LCIS	Rainfall	35^{0}17'10"	33053'04"	39	1978-2011
Karpass Peninsula Region							
Mehmetçik	17545	LCMH	Rainfall	35^{0}25'20"	34004'42"	99	1978-2011
Yenierenköy	17550	LCYE	Rainfall	35^{0}32'08"	34011'22"	123	1978-2011
Dipkarpaz	17547	LCDP	Rainfall	35^{0}35'56"	34022'45"	136	1978-2011

APPENDIX B

Table B.1 Trend analysis results of precipitation in North Cyprus for each season

T values (Sen's T test)

West Mesaoria Plain Region	**Spring (M,A,M)**	**Summer (J,J,A)**	**Fall (S,O,N)**	**Winter (D,J,F)**
Zumrutkoy	—	—	—	—
Lefke	—	—	—	—
Guzelyurt	—	↓	—	—
Yesilirmak	—	—	—	—
Gaziveren	—	↓	—	—

Z-Values (Mann-Kendal Test)

West Mesaoria Plain Region	**Spring (M,A,M)**	**Summer (J,J,A)**	**Fall (S,O,N)**	**Winter (D,J,F)**
Zumrutkoy	—	—	—	—
Lefke	—	—	—	—
Guzelyurt	—	↓	—	—
Yesilirmak	—	—	—	—
Gaziveren	—	↓	—	—

values (Sen's T test)

North Coast and Kyrenia Mountains Region	**Spring (M,A,M)**	**Summer (J,J,A)**	**Fall (S,O,N)**	**Winter (D,J,F)**
Camlibel	—	—	↑	—
Akdeniz	—	—	—	—
Girne	—	—	—	—
Alevkayası	—	—	—	—
Kantara	—	—	—	—

Z-Values (Mann Kendal Test)

North Coast and Kyrenia Mountains Region	**Spring (M,A,M)**	**Summer (J,J,A)**	**Fall (S,O,N)**	**Winter (D,J,F)**
Camlibel	—	—	↑	—
Akdeniz	—	—	—	—
Girne	—	—	—	—
Alevkayası	—	↑	—	—
Kantara	—	—	—	—

Table B.1 Trend analysis results of precipitation in North Cyprus for each season (con’t)

T values (Sen's T test)

Middle Mesaoria Plain Region	**Spring (M,A,M)**	**Summer (J,J,A)**	**Fall (S,O,N)**	**Winter (D,J,F)**
Alaykoy	—	—	—	—
Lefkosa	—	—	—	—
Ercan	—	—	—	—

Z-Values (Mann-Kendal Test)

Middle Mesaoria Plain Region	**Spring (M,A,M)**	**Summer (J,J,A)**	**Fall (S,O,N)**	**Winter (D,J,F)**
Alaykoy	—	—	—	—
Lefkosa	—	—	—	—
Ercan	—	—	—	—

T values (Sen's T test)

East Mesaoria Plain Region	**Spring (M,A,M)**	**Summer (J,J,A)**	**Fall (S,O,N)**	**Winter (D,J,F)**
Gecitkale	—	—	—	—
Dortyol	—	—	—	—

Z-Values (Mann-Kendal Test)

East Mesaoria Plain Region	**Spring (M,A,M)**	**Summer (J,J,A)**	**Fall (S,O,N)**	**Winter (D,J,F)**
Gecitkale	—	—	—	—
Dortyol	—	—	—	—

T values (Sen's T test)

Karpass Peninsula Region	**Spring (M,A,M)**	**Summer (J,J,A)**	**Fall (S,O,N)**	**Winter (D,J,F)**
Mehmetcik	—	—	—	—
Yenierenkoy	↓	—	—	—
Dipkarpaz	—	—	—	—

Z-Values (Mann-Kendal Test)

Karpass Peninsula Region	**Spring (M,A,M)**	**Summer (J,J,A)**	**Fall (S,O,N)**	**Winter (D,J,F)**
Mehmetcik	—	—	—	—
Yenierenkoy	↓	—	↓	—
Dipkarpaz	—	—	—	—

Table B.1 Trend analysis results of precipitation in North Cyprus for each season (con’t)

T values (Sen's T test)				
East Coast Region	**Spring (M,A,M)**	**Summer (J,J,A)**	**Fall (S,O,N)**	**Winter (D,J,F)**
Magusaub	—	↓	—	—
Iskele	—	—	—	—
Z-Values (Mann-Kendal Test)				
East Coast Region	**Spring (M,A,M)**	**Summer (J,J,A)**	**Fall (S,O,N)**	**Winter (D,J,F)**
Magusa	—	↓	—	—
Iskele	—	—	—	—

APPENDIX C

Table C.1 T and Z values for average of monthly maximum temperature (critical value: 1.64). Blue and bold color indicates significant trends.

T-Values	**Sen's T test**												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
YeniErenkoyMonthlyAv(Max)	0,36	0,65	**2,08**	1,31	1,27	**2,86**	1,42	**1,92**	**1,82**	0,83	1,52	0,26	**2,34**
MagosaMonthlyAv(Max)	0,43	0,5	**1,72**	0,56	0,87	1,55	**1,71**	**2,01**	0,55	0,07	1,14	1,59	**2**
LefkosaMonthlyAv(Max)	1,17	1,08	**2,08**	**1,7**	1,08	**2,15**	**3,08**	**3,38**	0,8	0,75	**1,68**	**1,73**	**3,7**
GuzelyurtMonthlyAv(Max)	0,63	0,26	1,49	1,28	0,64	1,43	**2,12**	**1,71**	0,86	0,32	1,03	1,19	**2,66**
GirneMonthlyAv(Max)	1,49	0,89	**2,56**	**2,03**	0,78	1,41	1,5	**2,98**	1,58	1,49	**2,38**	**1,71**	**3,16**
ErcanMonthlyAv(Max)	0,59	0,55	**1,64**	1,11	0,83	**2,11**	**2,6**	**3,37**	0,85	0,46	1,44	0,87	**3,02**
CamlibelMonthlyAv(Max)	1,07	-0,02	0,57	0,04	0,32	0,15	-0,23	0,9	0,01	-0,77	0,41	0,63	0,93
AlevkayasiMonthlyAv(Max)	-0,89	-0,26	0,84	0,35	-0,72	-0,04	0,55	1,4	-0,77	-0,41	0,52	-0,35	0,3

Z-Values	**Mann-Kendall Test**												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
YeniErenkoyMonthlyAv(Max)	1,11	1,13	**2,02**	1,63	1,05	**2,18**	**3,07**	**3,4**	0,7	0,67	1,62	**1,77**	**3,8**
MagosaMonthlyAv(Max)	0,59	0,65	**1,64**	0,34	0,73	**1,89**	**2,05**	**2,05**	0,55	0	1,16	1,44	**2,03**
LefkosaMonthlyAv(Max)	1,11	1,13	**2,02**	**1,63**	1,05	**2,19**	**3,07**	**3,4**	0,7	0,67	1,62	**1,77**	**3,8**
GuzelyurtMonthlyAv(Max)	0,59	0,27	1,48	1,2	0,53	1,28	**2,03**	**1,63**	0,74	0,39	1,02	1,1	**2,43**
GirneMonthlyAv(Max)	1,38	1,17	**2,49**	**1,66**	0,64	1,43	1,48	**3,06**	**1,71**	1,31	**2,3**	1,5	**3,1**
ErcanMonthlyAv(Max)	0,61	0,7	**1,64**	0,99	**0,82**	**2,12**	**2,66**	**3,4**	0,71	0,5	1,37	0,86	**2,89**
CamlibelMonthlyAv(Max)	0,99	-0,1	0,49	0,01	0,3	0,28	-0,13	0,94	0	-0,61	0,34	0,77	1,04
AlevkayasiMonthlyAv(Max)	-0,7	-0,12	0,64	0,3	-0,61	0,06	0,42	1,35	-0,7	-0,3	0,37	-0,33	0,22

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APPENDIX D

Table D.1 T and Z values for average of monthly minimum temperature (critical value: 1.64). Blue and bold color indicates significant trends

T-Values	**Sen's T test**												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
YeniErenkoyMonthlyAv(Tmin)	**3,38**	**2,98**	**3,04**	**3,60**	**4,28**	**4,21**	**3,70**	**3,95**	**3,63**	**3,65**	**3,61**	**3,96**	**4,78**
MagosaMonthlyAv(Tmin)	**1,75**	1,42	**2,30**	**2,59**	**3,77**	**4,74**	**4,45**	**4,68**	**3,34**	**3,59**	1,22	**2,65**	**4,57**
LefkosaMonthlyAv(Tmin)	0,83	1,34	**1,82**	1,63	1,64	**3,27**	**2,59**	**2,96**	**2,77**	1,49	0,55	0,85	**2,61**
GuzelyurtMonthlyAv(Tmin)	1,29	1,09	**1,65**	1,44	**2,46**	**3,73**	**3,85**	**4,46**	**3,93**	**2,46**	0,80	1,14	**3,98**
GirneMonthlyAv(Tmin)	**3,00**	**3,88**	**4,24**	**4,65**	**4,98**	**5,06**	**5,03**	**5,07**	**5,23**	**4,65**	**3,54**	**3,77**	**5,35**
ErcanMonthlyAv(Tmin)	-0,53	-0,20	-0,29	-0,18	0,92	1,53	1,55	**2,20**	**1,65**	0,94	-0,39	-0,08	0,90
CamlibelMonthlyAv(Tmin)	0,99	1,22	**2,55**	1,61	**3,34**	**3,06**	**3,11**	**3,66**	**2,73**	**1,79**	0,73	1,54	**3,41**
AlevkayasiMonthlyAv(Tmin)	**2,68**	**2,68**	**3,56**	**3,14**	**2,50**	**3,42**	**2,78**	**3,92**	**3,50**	**2,55**	**2,08**	**2,06**	**4,18**

Z-Values	**Mann-Kendall Test**												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
YeniErenkoyMonthlyAv(Tmin)	**3,32**	**3,22**	**3,19**	**3,80**	**4,70**	**4,48**	**3,72**	**4,05**	**3,86**	**3,78**	**3,92**	**3,84**	**5,16**
MagosaMonthlyAv(Tmin)	**1,84**	1,51	**2,36**	**2,60**	**4,02**	**5,37**	**5,00**	**5,27**	**3,44**	**3,98**	1,32	**2,61**	**4,89**
LefkosaMonthlyAv(Tmin)	0,89	1,26	**1,69**	1,41	**2,02**	**3,61**	**2,86**	**3,09**	**2,75**	1,57	0,65	0,68	**2,95**
GuzelyurtMonthlyAv(Tmin)	1,17	1,36	1,42	1,56	**2,37**	**3,86**	**4,01**	**4,79**	**4,11**	**2,51**	0,67	1,01	**4,02**
GirneMonthlyAv(Tmin)	**2,95**	**4,07**	**4,49**	**5,21**	**5,62**	**5,82**	**5,82**	**5,80**	**6,34**	**5,10**	**3,74**	**3,85**	**6,51**
ErcanMonthlyAv(Tmin)	-0,59	-0,07	-0,24	-0,30	0,95	1,49	1,36	**2,14**	**1,72**	0,94	-0,37	-0,27	0,59
CamlibelMonthlyAv(Tmin)	0,93	1,34	**2,35**	1,45	**3,19**	**2,94**	**3,03**	**3,61**	**2,70**	1,51	0,77	1,45	**3,25**
AlevkayasiMonthlyAv(Tmin)	**2,66**	**2,89**	**3,50**	**2,97**	**2,29**	**3,49**	**2,86**	**3,69**	**3,54**	**2,31**	**2,06**	**1,77**	**4,14**

APPENDIX E

Trend analysis results for temperature variable at eight temperature stations in each month.

Table E.1 Trend analysis results in January temperature of North Cyprus.

Temperature	YeniErenköy	Gazi Magosa	Lefkoşa	Guüzelyurt	Girne	Ercan	Çamlıbel	Alevkayası
av(Tav)								
Seasonal Sen's T Test	↑	—	—	—	↑	—	—	—
Seasonal Mann-Kendall Test	↑	—	—	—	↑	—	—	—
min(Tmin)								
Seasonal Sen's T Test	↑	—	—	—	↑	—	—	—
Seasonal Mann-Kendall Test	↑	—	—	↑	↑	—	—	—
av(Tmin)								
Seasonal Sen's T Test	↑	↑	—	—	↑	—	—	↑
Seasonal Mann-Kendall Test	↑	↑	—	—	↑	—	—	↑
max(Tmax)								
Seasonal Sen's T Test	—	—	—	—	—	↑	—	—
Seasonal Mann-Kendall Test	—	—	—	—	—	—	—	—
av(Tmax)								
Seasonal Sen's T Test	—	—	—	—	—	—	—	—
Seasonal Mann-Kendall Test	—	—	—	—	—	—	—	—
Diurnal Temp.								
Seasonal Sen's T Test	↓	—	—	—	↓	—	—	↓
Seasonal Mann-Kendall Test	↓	—	—	—	↓	—	—	↓

Table E.2 Trend analysis results in February temperature of North Cyprus.

Temperature	**YeniErenköy**	**Gazi Magosa**	**Lefkoşa**	**Guüzelyurt**	**Girne**	**Ercan**	**Çamlıbel**	**Alevkayası**
av(Tav)								
Seasonal Sen's T Test	—	—	—	—	↑	—	—	—
Seasonal Mann-Kendall Test	—	—	—	—	↑	—	—	—
min(Tmin)								
Seasonal Sen's T Test	↑	—	—	—	↑	—	—	—
Seasonal Mann-Kendall Test	↑	—	—	—	↑	—	—	—
av(Tmin)								
Seasonal Sen's T Test	↑	—	—	—	↑	—	—	↑
Seasonal Mann-Kendall Test	↑	—	—	—	↑	—	—	↑
max(Tmax)								
Seasonal Sen's T Test	—	—	↑	—	—	—	—	—
Seasonal Mann-Kendall Test	—	—	↑	↑	—	—	—	—
av(Tmax)								
Seasonal Sen's T Test	—	—	—	—	—	—	—	—
Seasonal Mann-Kendall Test	—	—	—	—	—	—	—	—
Diurnal Temp.								
Seasonal Sen's T Test	↓	—	—	—	↓	—	—	↓
Seasonal Mann-Kendall Test	↓	—	—	—	↓	—	—	↓

Table E.3 Trend analysis results in March temperature of North Cyprus

Temperature	YeniErenköy	Gazi Magosa	Lefkoşa	Guüzelyurt	Girne	Ercan	Çamlıbel	Alevkayası
av(Tav)								
Seasonal Sen's T Test	↑	↑	—	—	↑	—	—	↑
Seasonal Mann-Kendall Test	↑	↑	↑	—	↑	—	—	—
min(Tmin)								
Seasonal Sen's T Test	↑	↑	—	↑	↑	—	↑	↑
Seasonal Mann-Kendall Test	↑	↑	—	↑	↑	—	—	↑
av(Tmin)								
Seasonal Sen's T Test	↑	↑	↑	↑	↑	—	↑	↑
Seasonal Mann-Kendall Test	↑	↑	↑	—	↑	—	↑	↑
max(Tmax)								
Seasonal Sen's T Test	—	—	—	—	—	—	—	—
Seasonal Mann-Kendall Test	—	—	—	—	—	—	—	—
av(Tmax)								
Seasonal Sen's T Test	↑	↑	↑	—	↑	↑	—	—
Seasonal Mann-Kendall Test	↑	↑	↑	—	↑	↑	—	—
Diurnal Temp.								
Seasonal Sen's T Test	↓	—	—	—	↓	↑	—	↓
Seasonal Mann-Kendall Test	↓	—	—	—	↓	↑	—	↓

Table E.4 Trend analysis results in April temperature of North Cyprus

Temperature	**YeniErenköy**	**Gazi Magosa**	**Lefkoşa**	**Guüzelyurt**	**Girne**	**Ercan**	**Çamlıbel**	**Alevkayası**
av(Tav)								
Seasonal Sen's T Test	↑	↑	—	—	↑	—	—	↑
Seasonal Mann-Kendall Test	↑	↑	—	—	↑	—	—	↑
min(Tmin)								
Seasonal Sen's T Test	↑	↑	—	—	↑	—	↑	↑
Seasonal Mann-Kendall Test	↑	↑	—	—	↑	—	↑	↑
av(Tmin)								
Seasonal Sen's T Test	↑	↑	↑	—	↑	—	↑	↑
Seasonal Mann-Kendall Test	↑	↑	—	—	↑	—	—	↑
max(Tmax)								
Seasonal Sen's T Test	—	—	—	—	—	—	—	—
Seasonal Mann-Kendall Test	—	—	—	—	—	—	—	—
av(Tmax)								
Seasonal Sen's T Test	—	—	↑	—	↑	—	—	—
Seasonal Mann-Kendall Test	↑	—	↑	—	↑	—	—	—
Diurnal Temp.								
Seasonal Sen's T Test	↓	↓	—	—	↓	—	↓	↓
Seasonal Mann-Kendall Test	↓	↓	—	—	↓	—	↓	↓

Table E.5 Trend analysis results in May temperature of North Cyprus

Temperature	**YeniErenköy**	**Gazi Magosa**	**Lefkoşa**	**Guüzelyurt**	**Girne**	**Ercan**	**Çamlıbel**	**Alevkayası**
av(Tav)								
Seasonal Sen's T Test	↑	↑	—	↑	↑	—	—	—
Seasonal Mann-Kendall Test	↑	—	—	↑	↑	—	—	—
min(Tmin)								
Seasonal Sen's T Test	↑	↑	—	↑	↑	—	↑	↑
Seasonal Mann-Kendall Test	↑	↑	—	↑	↑	—	↑	↑
av(Tmin)								
Seasonal Sen's T Test	↑	↑	↑	↑	↑	—	↑	↑
Seasonal Mann-Kendall Test	↑	↑	↑	↑	↑	—	↑	↑
max(Tmax)								
Seasonal Sen's T Test	—	—	—	—	↓	—	—	—
Seasonal Mann-Kendall Test	—	—	—	—	—	—	—	—
av(Tmax)								
Seasonal Sen's T Test	—	—	—	—	—	—	—	—
Seasonal Mann-Kendall Test	—	—	—	—	—	—	—	—
Diurnal Temp.								
Seasonal Sen's T Test	↓	↓	—	—	↓	—	↓	↓
Seasonal Mann-Kendall Test	↓	↓	—	—	↓	—	↓	↓

Table E.6 Trend analysis results in June temperature of North Cyprus

Temperature	**YeniErenköy**	**Gazi Magosa**	**Lefkoşa**	**Guüzelyurt**	**Girne**	**Ercan**	**Çamlıbel**	**Alevkayası**
av(Tav)								
Seasonal Sen's T Test	↑	↑	↑	↑	↑	↑	—	—
Seasonal Mann-Kendall Test	↑	↑	↑	↑	↑	↑	—	↑
min(Tmin)								
Seasonal Sen's T Test	↑	↑	↑	↑	↑	—	↑	↑
Seasonal Mann-Kendall Test	↑	↑	↑	↑	↑	—	↑	↑
av(Tmin)								
Seasonal Sen's T Test	↑	↑	↑	↑	↑	—	↑	↑
Seasonal Mann-Kendall Test	↑	↑	↑	↑	↑	—	↑	↑
max(Tmax)								
Seasonal Sen's T Test	—	—	—	—	—	—	—	—
Seasonal Mann-Kendall Test	—	—	—	—	—	—	—	—
av(Tmax)								
Seasonal Sen's T Test	↑	—	↑	—	—	↑	—	—
Seasonal Mann-Kendall Test	↑	↑	↑	—	—	↑	—	—
Diurnal Temp.								
Seasonal Sen's T Test	↓	↓	—	—	↓	—	↓	↓
Seasonal Mann-Kendall Test	↓	↓	↓	—	↓	—	↓	↓

Table E.7 Trend analysis results in July temperature of North Cyprus

Temperature	**YeniErenköy**	**Gazi Magosa**	**Lefkoşa**	**Guüzelyurt**	**Girne**	**Ercan**	**Çamlıbel**	**Alevkayası**
av(Tav)								
Seasonal Sen's T Test	↑	↑	↑	↑	↑	↑	—	↑
Seasonal Mann-Kendall Test	—	↑	↑	↑	↑	↑	—	↑
min(Tmin)								
Seasonal Sen's T Test	↑	↑	↑	↑	↑	—	↑	↑
Seasonal Mann-Kendall Test	↑	↑	↑	↑	↑	—	↑	↑
av(Tmin)								
Seasonal Sen's T Test	↑	↑	↑	↑	↑	—	↑	↑
Seasonal Mann-Kendall Test	↑	↑	↑	↑	↑	—	↑	↑
max(Tmax)								
Seasonal Sen's T Test	—	—	—	—	—	—	↓	—
Seasonal Mann-Kendall Test	—	—	—	—	—	—	↓	—
av(Tmax)								
Seasonal Sen's T Test	—	↑	↑	↑	—	↑	—	—
Seasonal Mann-Kendall Test	↑	↑	↑	↑	—	↑	—	—
Diurnal Temp.								
Seasonal Sen's T Test	↓	↓	—	—	↓	↑	↓	↓
Seasonal Mann-Kendall Test	↓	↓	—	—	↓	↑	↓	↓

Table E.8 Trend analysis results in August temperature of North Cyprus

Temperature	**YeniErenköy**	**Gazi Magosa**	**Lefkoşa**	**Guüzelyurt**	**Girne**	**Ercan**	**Çamlıbel**	**Alevkayası**
av(Tav)								
Seasonal Sen's T Test	↑	↑	↑	↑	↑	↑	—	↑
Seasonal Mann-Kendall Test	↑	↑	↑	↑	↑	↑	—	↑
min(Tmin)								
Seasonal Sen's T Test	↑	↑	↑	↑	↑	↑	↑	↑
Seasonal Mann-Kendall Test	↑	↑	↑	↑	↑	↑	↑	↑
av(Tmin)								
Seasonal Sen's T Test	↑	↑	↑	↑	↑	↑	↑	↑
Seasonal Mann-Kendall Test	↑	↑	↑	↑	↑	↑	↑	↑
max(Tmax)								
Seasonal Sen's T Test	↑	—	↑	↑	—	↑	—	—
Seasonal Mann-Kendall Test	↑	—	↑	↑	—	↑	—	—
av(Tmax)								
Seasonal Sen's T Test	↑	↑	↑	↑	↑	↑	—	—
Seasonal Mann-Kendall Test	↑	↑	↑	↑	↑	↑	—	—
Diurnal Temp.								
Seasonal Sen's T Test	↓	↓	—	↓	↓	—	↓	↓
Seasonal Mann-Kendall Test	↓	↓	—	↓	↓	—	↓	↓

Table E.9 Trend analysis results in September temperature of North Cyprus

Temperature	YeniErenköy	Gazi Magosa	Lefkoşa	Guüzelyurt	Girne	Ercan	Çamlıbel	Alevkayası
av(Tav)								
Seasonal Sen's T Test	↑	↑	—	↑	↑	—	—	↑
Seasonal Mann-Kendall Test	↑	↑	—	↑	↑	—	—	↑
min(Tmin)								
Seasonal Sen's T Test	↑	↑	—	↑	↑	—	↑	↑
Seasonal Mann-Kendall Test	↑	↑	—	↑	↑	—	↑	↑
av(Tmin)								
Seasonal Sen's T Test	↑	↑	↑	↑	↑	↑	↑	↑
Seasonal Mann-Kendall Test	↑	↑	↑	↑	↑	↑	↑	↑
max(Tmax)								
Seasonal Sen's T Test	—	—	—	—	—	—	—	↑
Seasonal Mann-Kendall Test	—	—	—	—	—	—	—	—
av(Tmax)								
Seasonal Sen's T Test	↑	—	—	—	—	—	—	—
Seasonal Mann-Kendall Test	—	—	—	—	↑	—	—	—
Diurnal Temp.								
Seasonal Sen's T Test	↓	↓	—	↓	↓	—	↓	↓
Seasonal Mann-Kendall Test	↓	↓	—	↓	↓	—	↓	↓

Table E.10 Trend analysis results in October temperature of North Cyprus

Temperature	YeniErenköy	Gazi Magosa	Lefkoşa	Guüzelyurt	Girne	Ercan	Çamlıbel	Alevkayası
av(Tav)								
Seasonal Sen's T Test	↑	↑	—	—	↑	—	—	—
Seasonal Mann-Kendall Test	↑	↑	—	—	↑	—	—	—
min(Tmin)								
Seasonal Sen's T Test	↑	—	—	—	↑	—	—	—
Seasonal Mann-Kendall Test	↑	—	—	—	↑	—	—	—
av(Tmin)								
Seasonal Sen's T Test	↑	↑	—	↑	↑	—	↑	↑
Seasonal Mann-Kendall Test	↑	↑	—	↑	↑	—	—	↑
max(Tmax)								
Seasonal Sen's T Test	—	—	—	—	—	—	—	—
Seasonal Mann-Kendall Test	—	—	—	—	—	—	—	—
av(Tmax)								
Seasonal Sen's T Test	—	—	—	—	—	—	—	—
Seasonal Mann-Kendall Test	—	—	—	—	—	—	—	—
Diurnal Temp.								
Seasonal Sen's T Test	↓	↓	—	↓	↓	—	—	↓
Seasonal Mann-Kendall Test	↓	↓	—	↓	↓	—	—	↓

Table E.11 Trend analysis results in November temperature of North Cyprus

Temperature	**YeniErenköy**	**Gazi Magosa**	**Lefkoşa**	**Guüzelyurt**	**Girne**	**Ercan**	**Çamlıbel**	**Alevkayası**
av(Tav)								
Seasonal Sen's T Test	↑	—	—	—	↑	—	—	—
Seasonal Mann-Kendall Test	↑	—	—	—	↑	—	—	—
min(Tmin)								
Seasonal Sen's T Test	↑	—	—	—	↑	—	—	↑
Seasonal Mann-Kendall Test	↑	—	—	—	↑	—	—	↑
av(Tmin)								
Seasonal Sen's T Test	↑	—	—	—	↑	—	—	↑
Seasonal Mann-Kendall Test	↑	—	—	—	↑	—	—	↑
max(Tmax)								
Seasonal Sen's T Test	—	—	—	—	—	—	—	—
Seasonal Mann-Kendall Test	—	—	—	—	—	—	—	—
av(Tmax)								
Seasonal Sen's T Test	—	—	↑	—	↑	—	—	—
Seasonal Mann-Kendall Test	↑	—	↑	—	↑	—	—	—
Diurnal Temp.								
Seasonal Sen's T Test	↓	—	—	—	↓	↑	—	↓
Seasonal Mann-Kendall Test	↓	—	—	—	↓	↑	—	↓

Table E.12 Trend analysis results in December temperature of North Cyprus

Temperature	**YeniErenköy**	**Gazi Magosa**	**Lefkoşa**	**Güüzelyurt**	**Girne**	**Ercan**	**Çamlıbel**	**Alevkayası**
av(Tav)								
Seasonal Sen's T Test	↑	↑	—	—	↑	—	—	—
Seasonal Mann-Kendall Test	↑	↑	—	—	↑	—	—	—
min(Tmin)								
Seasonal Sen's T Test	↑	↑	—	—	↑	—	—	—
Seasonal Mann-Kendall Test	↑	↑	—	↑	↑	—	—	—
av(Tmin)								
Seasonal Sen's T Test	↑	↑	—	—	↑	—	—	↑
Seasonal Mann-Kendall Test	↑	↑	—	—	↑	—	—	↑
max(Tmax)								
Seasonal Sen's T Test	—	—	—	—	↑	—	—	—
Seasonal Mann-Kendall Test	—	—	—	—	↑	—	—	—
av(Tmax)								
Seasonal Sen's T Test	—	—	↑	—	↑	—	—	—
Seasonal Mann-Kendall Test	↑	—	↑	—	—	—	—	—
Diurnal Temp.								
Seasonal Sen's T Test	↓	—	—	—	↓	—	—	↓
Seasonal Mann-Kendall Test	↓	—	—	—	↓	—	—	↓

APPENDIX F

Trend analysis results for annual and seasonal temperature variables at eight temperature stations.

Table F.1 Trend analysis results for annual temperature variables of North Cyprus

Temperature	YeniErenköy	Gazi Magosa	Lefkoşa	Güüzelyurt	Girne	Ercan	Çamlıbel	Alevkayası
av(Tav)								
Seasonal Sen's T Test	↑	↑	↑	↑	↑	↑	—	↑
Seasonal Mann-Kendall Test	↑	↑	↑	↑	↑	↑	—	↑
min(Tmin)								
Seasonal Sen's T Test	↑	—	—	↑	↑	—	—	↑
Seasonal Mann-Kendall Test	↑	—	—	↑	↑	—	—	↑
av(Tmin)								
Seasonal Sen's T Test	↑	↑	↑	↑	↑	—	↑	↑
Seasonal Mann-Kendall Test	↑	↑	↑	↑	↑	—	↑	↑
max(Tmax)								
Seasonal Sen's T Test	↑	—	—	—	—	—	—	—
Seasonal Mann-Kendall Test	↑	—	—	—	—	—	—	—
av(Tmax)								
Seasonal Sen's T Test	↑	↑	↑	↑	↑	↑	—	—
Seasonal Mann-Kendall Test	↑	↑	↑	↑	↑	↑	—	—
Diurnal Temp.								
Seasonal Sen's T Test	↓	—	—	↓	↓	↑	—	↓
Seasonal Mann-Kendall Test	↓	—	—	↓	↓	↑	—	↓

Table F.2 Trend analysis results for seasonal temperature variables of North Cyprus

Temperature	YeniErenköy	Gazi Magosa	Lefkoşa	Guüzelyurt	Girne	Ercan	Çamlıbel	Alevkayası
av(Tav)								
Seasonal Sen's T Test	↑	↑	↑	↑	↑	↑	↑	↑
Seasonal Mann-Kendall Test	↑	↑	↑	↑	↑	↑	↑	↑
min(Tmin)								
Seasonal Sen's T Test	↑	↑	↑	↑	↑	—	↑	↑
Seasonal Mann-Kendall Test	↑	↑	↑	↑	↑	—	↑	↑
av(Tmin)								
Seasonal Sen's T Test	↑	↑	↑	↑	↑	↑	↑	↑
Seasonal Mann-Kendall Test	↑	↑	↑	↑	↑	↑	↑	↑
max(Tmax)								
Seasonal Sen's T Test	↑	—	↑	↑	—	↑	—	—
Seasonal Mann-Kendall Test	↑	—	↑	↑	—	↑	—	—
av(Tmax)								
Seasonal Sen's T Test	↑	↑	↑	↑	↑	↑	—	—
Seasonal Mann-Kendall Test	↑	↑	↑	↑	↑	↑	—	—
Diurnal Temp.								
Seasonal Sen's T Test	↓	↓	—	↓	↓	↑	↓	↓
Seasonal Mann-Kendall Test	↓	↓	—	↓	↓	↑	↓	↓

APPENDIX G

Spatial distributions of seasonal test results of precipitation and temperature variables

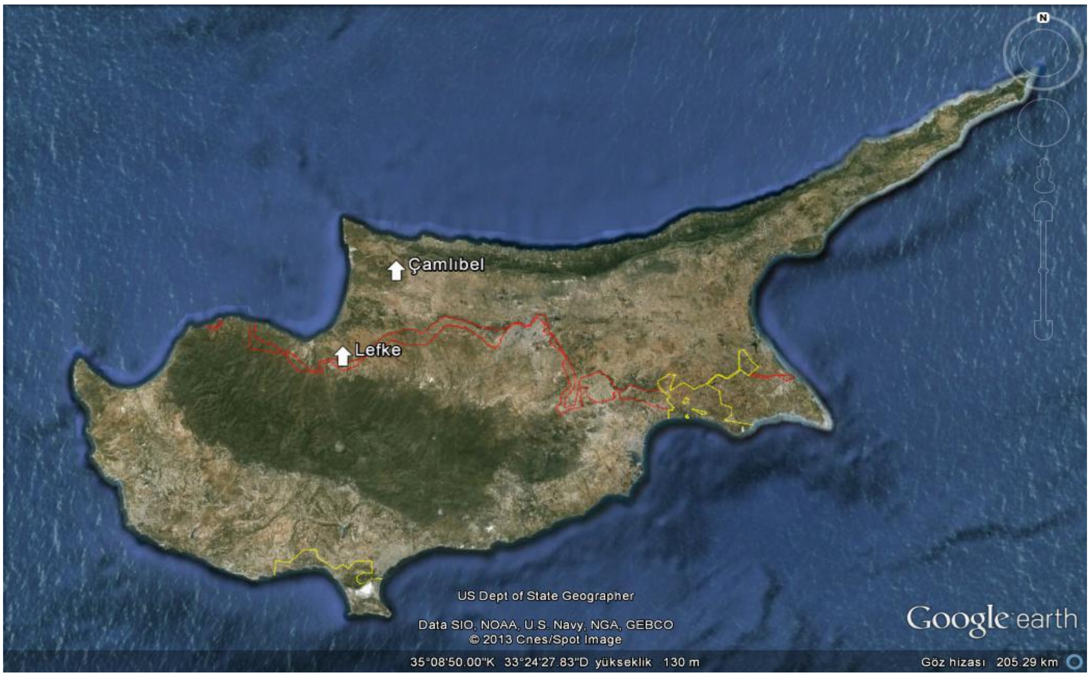

Figure G.1 Spatial distributions of seasonal trend test results of precipitation

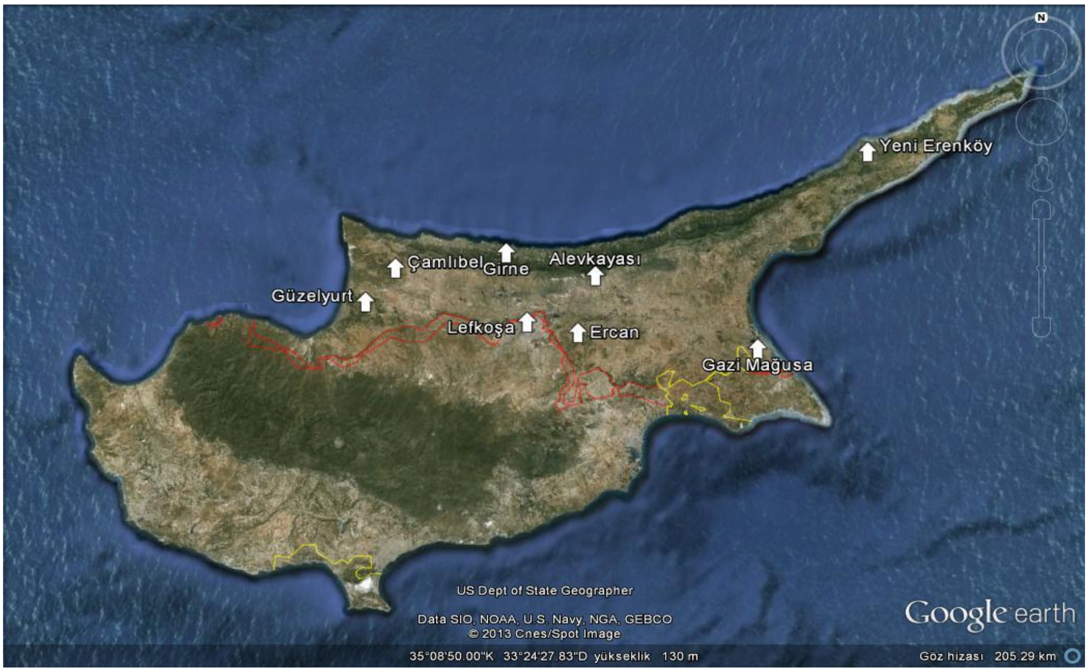

Figure G.2 Spatial distributions of seasonal trend test results of av(Tav)

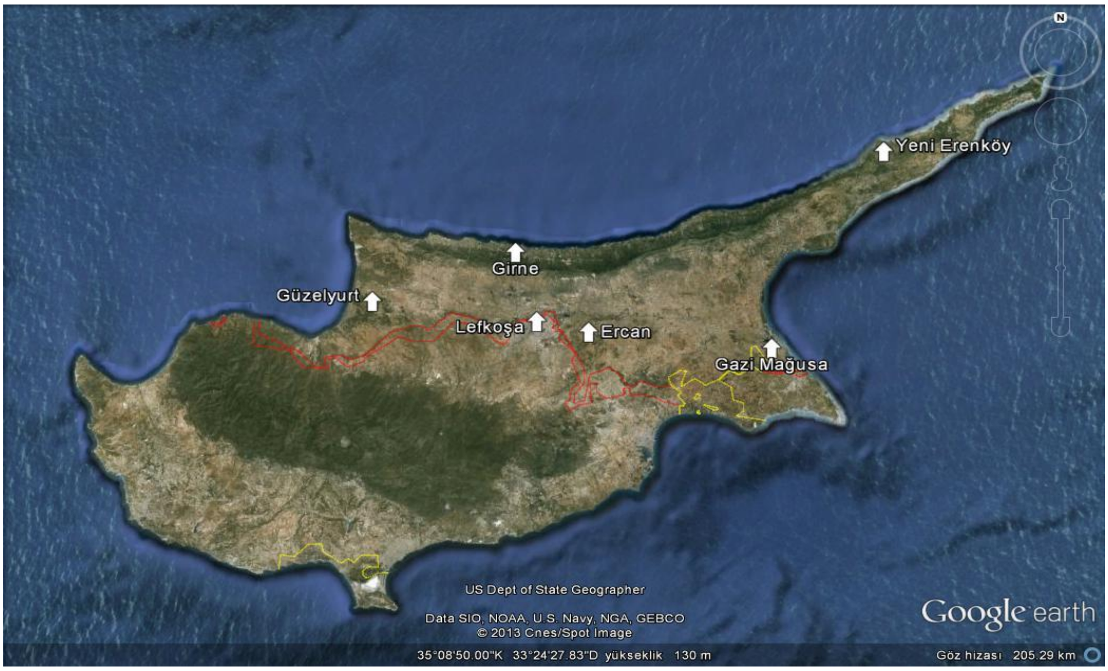

Figure G.3 Spatial distributions of seasonal trend test results of av(Tmax)

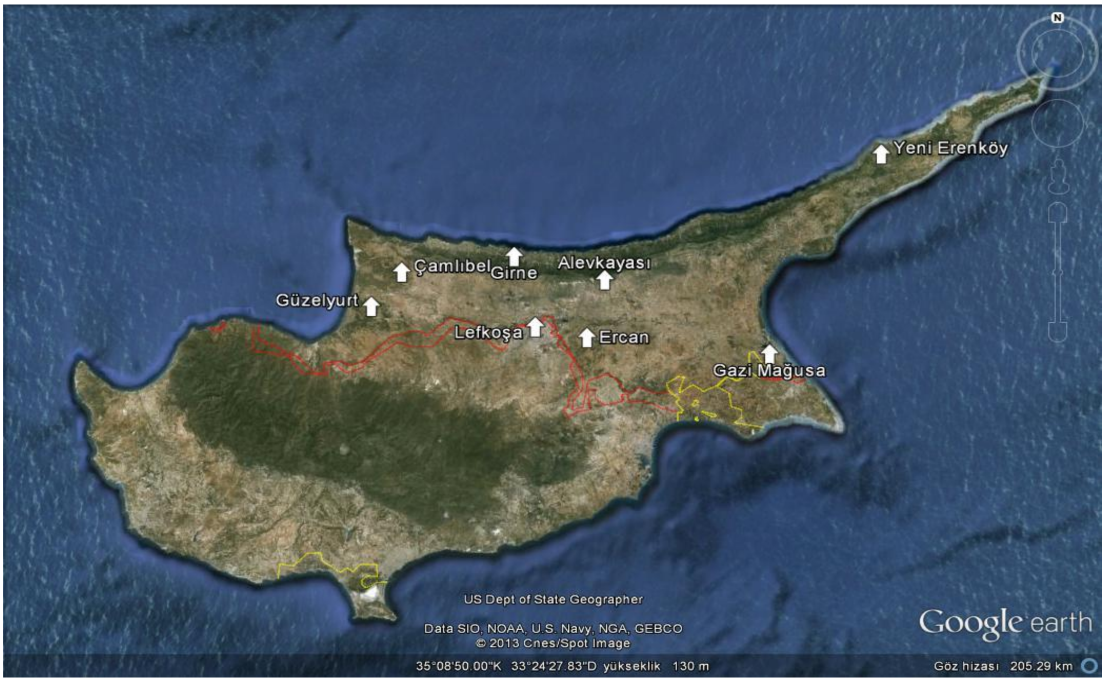

Figure G.4 Spatial distributions of seasonal trend test results of av(Tmin)

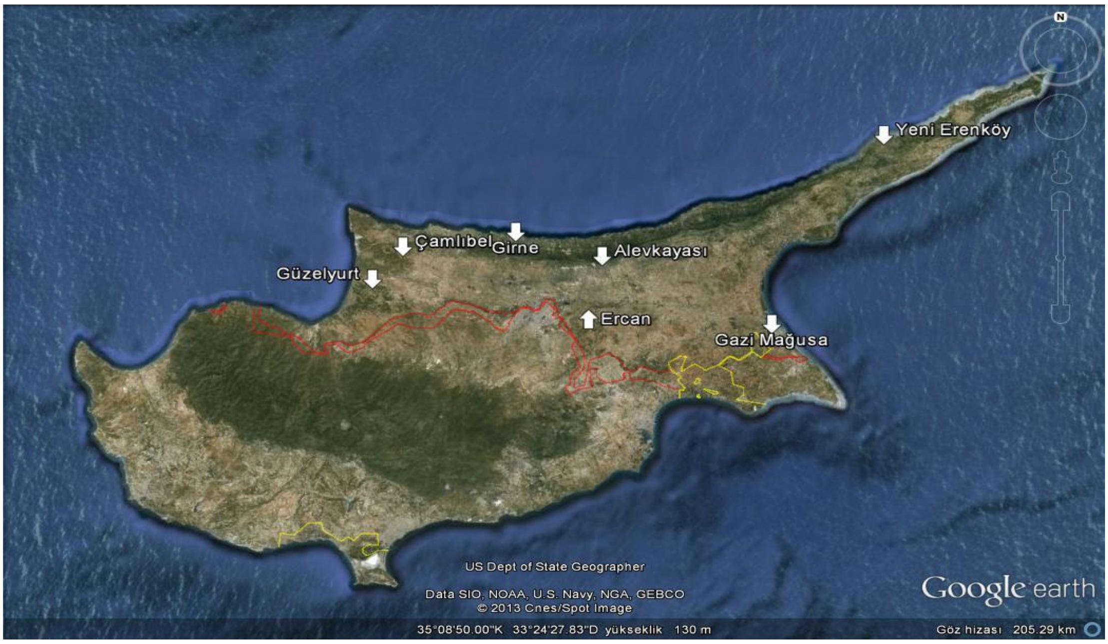

Figure G.5 Spatial distributions of seasonal trend test results of DTR

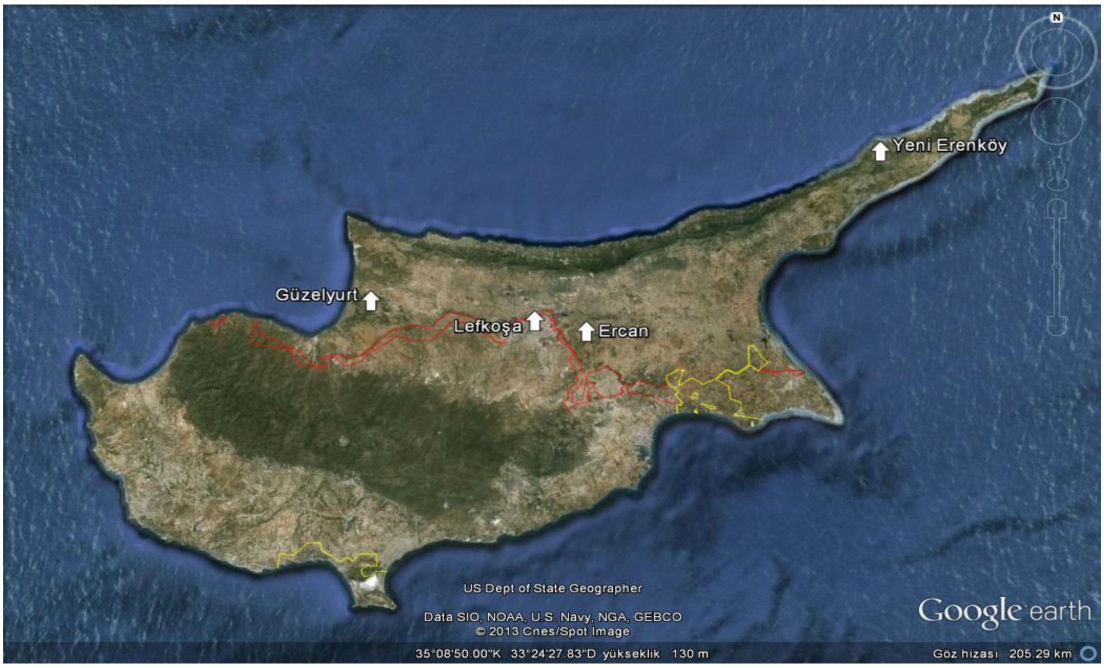

Figure G.6 Spatial distributions of seasonal trend test results of max(Tmax)

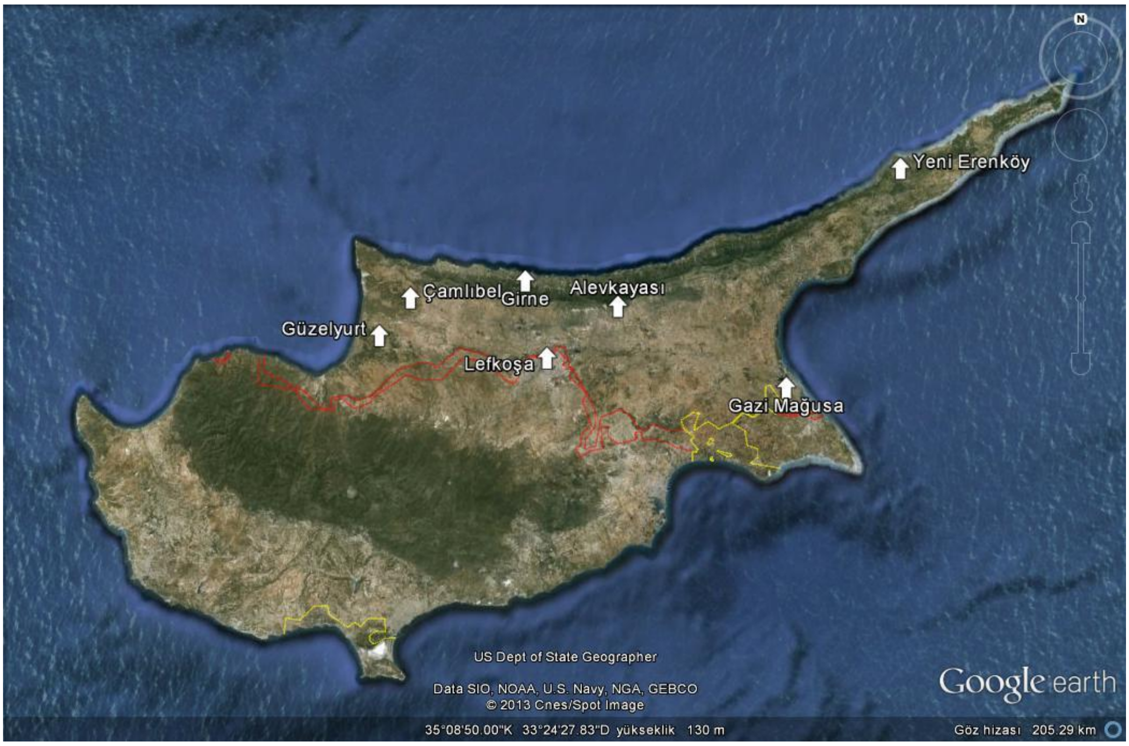

Figure G.7 Spatial distributions of seasonal trend test results of min(Tmin)