ANALYSIS OF SUNSHINE DURATION BETWEEN 1970 AND 2010 FOR TURKEY

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ABSTRACT

ANALYSIS OF SUNSHINE DURATION BETWEEN 1970 AND 2010 FOR TURKEY

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In this thesis, 41 years of bright sunshine duration (SD) data of 192 meteorological stations in Turkey were analyzed. The main objective is to determine the trends of SD data and the importance of such analyses is the high correlation between SD data and solar irradiation reaching the surface of the earth. Because of the missing value problems, only the data set for 72 stations were examined. After imputing missing values of these stations by expectation maximization algorithm, to test the homogeneity Kruskal Wallis test (K-W) and Wald-Wolfowitz runs test for randomness were applied. Only 36 of the stations passed from these homogeneity tests therefore, trend analysis was carried out for these locations. To exclude the data sets which did not pass from the tests was important to reach more accurate trend analysis of the data in hand.

Results of the trend analysis showed that the change of SD over the 41 years are in agreement with the globally identified surface solar radiation *dimming and brightening* time periods all over the world. The dimming period is mainly between the years 1970 and about 1990 while the brightening period is from about 1990 to 2010. The yearly averages of SD data sets of 27 locations out of 36, for the years in the dimming period, were in a good agreement with the global dimming trends. However, for the brightening period the agreement was not as clear as it was in the dimming period. Nevertheless, during the brightening period, the data set of most of the locations had zero trends or noticeably reduced rates of decrease of SD.

The dimming might be attributed to the increase in air pollution and this might be an indication of human induced climate change. Larger amounts of negative trends during winter months supported this conclusion. However, to reach a concrete conclusion more accurate of different climatic parameters should be analyzed. Satellites images may be helpful for further clarifications of such conclusions on climate change issues.

Keywords: Sunshine Duration, Surface Solar Radiation, Global Dimming and Brightening, Trend Analysis.

ÖZ

1970-2010 ARASINDA TÜRKİYE'DEKİ GÜNEŞLENME SÜRESİ VERİLERİNİN ANALİZİ

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Bu tezde Türkiye'deki 192 meteoroloji istasyonu için 41 yıllık güneşlenme süresi (GS) verisi analiz edildi. Tezin ana amacı GS verilerinin eğilimlerini belirlemektir. Bunun önemi GS verilerinin yer yüzeyine ulaşan güneş radyasyonu ile yüksek ilişki düzeyine sahip olmasından ileri gelir. Eksik veri probleminden ötürü sadece 72 istasyon verisi incelendi. Bu 72 istasyonun eksik verileri tamamlandıktan sonra Kruskal Wallis (K-W) testi ve Wald-Wolfowitz rastlantısallık testi uygulandı. Bu testlerden sadece 36 istasyon geçebildiği için eğilim analizleri bu 36 istasyon için yapıldı. Diğer veri kümeleri, eğilimleri daha hassas belirleyebilmek için analizden çıkarıldı.

Eğilim analizleri, GS'deki 41 yıllık değişimin küresel ölçekte belirlenen, yüzeye gelen güneş enerjisindeki *azalma ve artma* periyoduyla tutarlı olduğunu gösterdi. Azalma periyodu temel olarak 1970 ile 1990 civarı ve artma periyodu 1990 civarı ile 2010 arasıdır. GS verisi için 1970 ile 1990 civarı arasında 36 istasyondan 27'si için azalma trendi gözlenmiştir ve bu azalma küresel ölçekteki azalma ile ileri düzeyde tutarlılık gösterir. Fakat artma periyodu için böyle bir tutarlılık belirgin değildir. Artma döneminde çoğu istasyon için eğilim sıfırlanmış veya eğilim oranı azalmıştır.

Azalma eğilimini hava kirliğindeki artmaya bağlamak mümkündür ve bu insan faaliyetinin iklim değişikliği üzerindeki bir göstergesi olabilir. Kış aylarında daha fazla azalma eğilimi olması bu sonucu destekler niteliktedir. Ancak daha kesin sonuçlara ulaşmak için diğer iklimsel verilerinde analiz edilmesi gerekir. Uydu görüntüleri bu sonuçları daha da kesinleştirmek için faydalı olabilir.

Anahtar Sözcükler: Güneşlenme Süresi, Yüzeye Gelen Güneş Enerjisi, Küresel Azalma ve Artma, Eğilim Analizi

to the ones who held onto their water and soil

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Climates of the Earth are being studied more and more by the researchers due to the well-known phenomena global warming and climate change. The climate change is so important because it impresses the biological diversity and richness, human societies, economic activities, urban areas, agriculture etc. The climate systems are determined by many factors including change in plate tectonics, Earth's orbit, solar output and anthropogenic forcing (external forcing). Interactions among vegetation, land surface, oceans, ice sheets and the atmosphere and internal responses of vegetation, land surface, oceans, ice sheets and the atmosphere are the main internal mechanisms. So the climate is so complex and even a slight change in one of the parameters may have a huge impact on the overall system [1].

Solar irradiation reaching the Earth is the main forcing and it also couples with the anthropogenic impact. Solar energy enables the life in the Earth and largely governs the climatic conditions of our planet. The main part of the surface energy balance is the solar energy coming to the surface. In addition to this; solar energy manages evaporation and related hydrological processes such as snow and rain fall, glacier melt, plant photosynthesis, diurnal and seasonal changes of the surface temperatures [2]. Therefore, change or redistribution of solar energy incident on the surface has a crucial impact on the climate systems of the Earth.

Investigation of change in solar radiation is an important scientific study due to the mentioned reasons above. This investigation can be done via directly analyzing the solar radiation data at the ground level or proxy data such as sunshine duration (SD), diurnal temperature range, pan evaporation and satellite-derived radiation estimates [2].

These changes may be more historic or recent. For instance Milankovitch cycles which are related with change of the orbital parameters of the Earth affects the Earth climates in a wide range of time periods such as 10s or 100s of thousands of years. However, sunspots may be effective in tens of years. The changes before the last century are directly related to change in solar activity and orbital parameters of the Earth and changes of the intrinsic mechanism of the Sun-Earth-Atmosphere system. However, in the last few centuries, anthropogenic processes have also become effective in climate change, mostly because the human activities affect the transmission of solar irradiation through the atmosphere. Stanhill [3] claims that most probable reason of recent changes in solar irradiation incident on the Earth is the altering of the transmissivity of the atmosphere. In fact, change in transmissivity is related to the varying concentrations of aerosols in the atmosphere which are mainly the consequence of the human activities.

In this study, SD data of 36 stations which are taken from the Turkish State Meteorological Service (TSMS) has been analyzed to infer the variability of the solar radiation in Turkey and then this variability have been compared with the results of recent researches and with the changes of other climatic parameters. Annual and seasonal averages were calculated by using daily data and the analysis were conducted for these annual and seasonal averages.

1.2 Sunshine Duration and Solar Radiation

The measure of time in which the direct solar radiation is above a certain threshold is defined as sunshine duration (SD). This threshold is usually taken as 120 Wm^{-2} [4] and it mainly corresponds to times when the sun is not obstructed by the clouds. Recorders of the SD are the oldest and most robust kinds of instruments within the solar irradiation related records. SD has been measured since the end of the 19^{th} century and measurements is widely distributed around the world [2].

SD is mainly measured by using Campbell-Stokes sunshine recorders, a photo of which is given in Figure 1.1. These recorders are simple and rather low error rates, and solar irradiation estimates based on this data is less erroneous than some other direct irradiation measurement of the recorders such as actinographs and old pyranometers [5]. Campbell-Stokes recorders include a spherical glass lens, and this lens focuses the sunshine on sensitive recording Strip. Sensitive strips burns leaving a trace to record the sunshine period whenever the solar radiation exceeds the threshold value. The burnt parts of the paper are than summed and converted in a number of hours within a day. Periods of early sunrise and sunsets are not recorded because to leave a trace on recording paper, solar irradiation above a threshold value is required. Also the threshold value can change with respect to the humidity in air. Irradiation threshold which burns the paper can vary between 100-300 Wm^{-2}. So the measurement's sensitivity can change day to day [6].

Modeling of relation between SD and solar irradiation began with the studies of Kimball in 1919. But this study did not show a quantitative relation between SD and solar irradiation. Angström proposed an empirical linear formula in 1924 for the data of Stockholm. This formula is the base of the other empirical formulas appeared later in the literature. Angström's formula was

Figure 1.1. Campbell-Stokes recorder (Taken from TSMS web site)

$$H = H_c(0.25 + 0.75\frac{n}{N}) \qquad (1.1)$$

where H_c is the total solar irradiation incident on horizontal surface in a day when the sky is perfectly clear and H is the daily value in any day. And n is the observed daily value of SD and N is the maximum value (i.e. day length) in that day. However concept of solar irradiation on a perfectly clear sky depends on the site of interest and it may have varying regional values due to the variety of atmospheric conditions. It is not easy to have solar irradiation measurements of a clear day for a specific site on the Earth surface. Therefore, a modification is needed to replace H_C of the site of interest [6].

Prescott obtained a new regression equation in 1940 by using the data of Mount Stramlo Observatory in Canberra-Australia. This equation was

$$\frac{H}{H_0} = 0.25 + 0.54\frac{n}{N} \qquad (1.2)$$

where H is the monthly average daily solar irradiation on horizontal surface and H_0 is the monthly average daily solar irradiation outside the atmosphere, n is the daily average of SD in a month and N is the day length. In other words, H_0, that is, daily solar irradiation outside the atmosphere on a horizontal surface can be calculated for different locations on the surface of the Earth [7].

A general form of eqn. 1.2 may be given as:

$$\frac{H}{H_0} = a + b\frac{n}{N} \qquad (1.3)$$

a and b are the regression coefficients which are changing site to site. This final form of the equation is known as Angström-Prescott relation. The regression coefficients depend on the atmospheric disturbances, amount and type of clouds, month of the year, altitude of the region and reflectance of the Earth's surface [6].

Daily values of solar irradiation H is an important quantity in climate change aspects as it directly give the daily amount of solar irradiation at the Earth's surface. However, solar irradiation measuring stations at the Earth's surface are far from being adequate to measure the climate change of the globe. Nevertheless, solar irradiation estimation based on SD measurements can be used to obtain some information on the climate change of the Earth [8]. Direct use of the SD data is another possibility which might be more informative since the measured SD data would not be replaced by the results of a correlation like equation 1.3 [4]. Here in this thesis we directly use the SD data.

As given above, SD variations can be converted into SSR variations. A 5% variation in SD roughly corresponds to a 5 Wm^{-2} change in SSR. The order of the SSR variations is up to 10% depending on the site [2]. In magnitude, SSR values can vary up to around 15 Wm^{-2} but this is an extreme value. For instance for mid-latitudes the average variability is around 4 Wm^{-2} [2].

1.3 Global Dimming and Brightening

The sum of the direct and diffuse solar irradiation coming to the surface of the Earth is defined as surface solar radiation (SSR). SSR is also called as global solar irradiation. As mentioned above, the solar irradiation at the surface of the Earth is not constant and SSR is changing from place to place. However, long term yearly variation at a locality on the surface of the Earth might give important information about the climate change on the surface of the Earth. For quite a lot of stations, there are strong evidences given in various studies that SSR value decreases between the 1950s and 1980s and increases after the 1980s. These results are usually called as *global dimming* which is followed by a *global brightening* [2].

Widespread measurements of SSR began in the international geophysical year (1957-1958). In these measurements thermopile pyranometers were used. Most of the measurements are collected in the Global Energy Balance Archive (GEBA) in Zurich and World Radiation Data Centre (WRDC) in Petersburg. Locations of stations are given in Figure 1.2. [2] The study of Gilgen et al. [9] by using 1500 stations shows that random error of these measurements is approximately 2% in yearly averages.

Measurement quality of national weather services is changing from site to site. Due to this reason the Baseline Surface Radiation Network (BSRN) has been founded within the scope of World Climate Research Programme (WCRP). Stations which have instruments of highest possible accuracy began to record SSR measurements at the beginning of 1990s [1,6]. Some other radiation networks have been founded in recent years. These are the Atmospheric Radiation Measurement (ARM) Program, the surface radiation (SURFAD) network which was founded by the National Oceanic and Atmospheric Administration (NOAA), the NOAA Earth System Research Laboratory (ESRL) Network, the Australian Network founded by the Bureau of Meteorology and the Alpine Surface Radiation Budget network (ASRB) [2]. Locations of these sites are given in Figure 1.3. It should be noted that accurate measurements of SSR that can enlighten the climate change issues are started recently and data is not adequately accumulated yet. To trace the impact of human on the climate change however one should go back to early dates of industrialization.

In addition to the sites given in Figure 1.2 and Figure 1.3 there are regional studies about SSR dealing with the *global dimming and brightening* periods. Periods and regions of these studies can be seen in Table 1.1 and Table 1.2 which are taken from the study of Wild [2].

Table 1.1 and Table 1.2 give relative and absolute trend value of each study for widely distributed and regional researches. It is shown in Table 1.1 that there is a decreasing trend between the end of 1960s and end of 1980s and it is shown in Table 1.2 that most of the sites have increasing trend after the end of 1980s. Only study of Wild between 2000-2005 in China and Padma Kumari et al. between 1984-2001 in India have negative trends after the end of 1980s. Results of studies showed in Table 1.1 and 1.2 gives strong evidences for the *global dimming and brightening*.

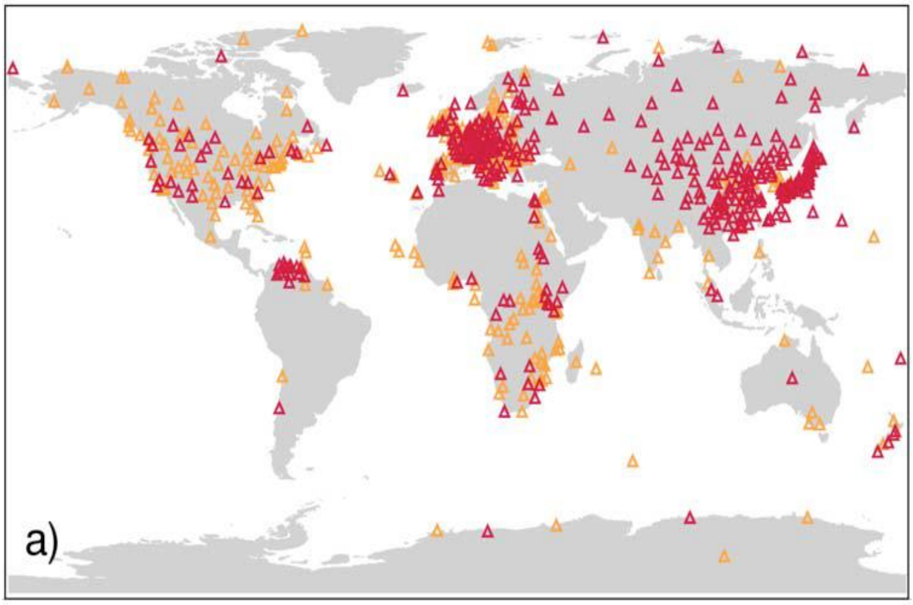

Figure 1.2. Distribution of GEBA/WRDC stations. Orange triangles represent the stations which have more than 10 years measurement range. Red ones represent the stations which have more than 20 years measurement range (most of them going back to the 1960s). Figure was taken from Wild's study [2].

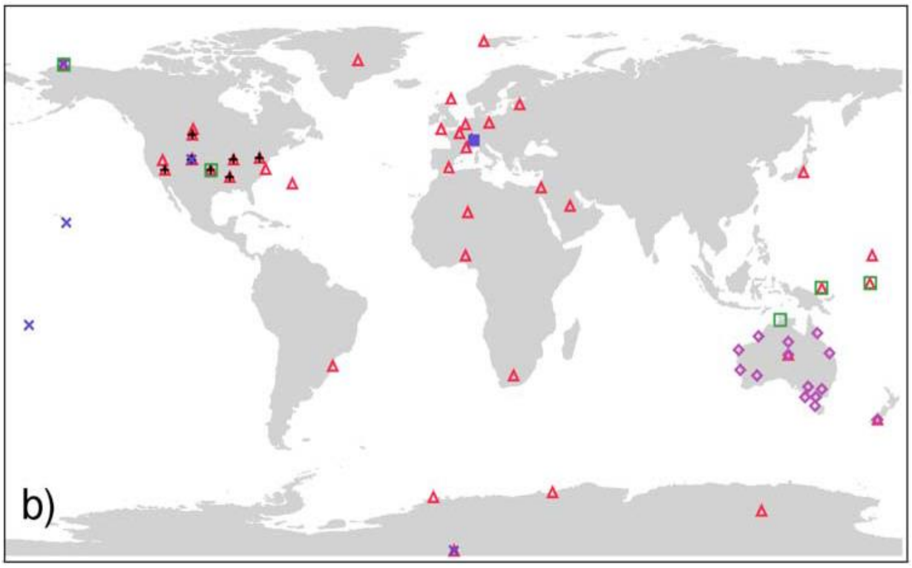

Figure 1.3. Distribution of other non-local stations. Red triangles are sites of BSRN, red squares are sites of ARM, black plus signs are sites of NOAA/SURFRAD, blue crosses are sites of NOAA/ESRL, purple diamonds are sites of Australian Network and blue squares are sites of ASRB. Figure was taken from Wild's study [2].

Surface measurements for SSR data do not represent the global scale adequately. So, satellite derived data might be needed because satellites supply data for the oceans and lands by remote means. The satellites do not measure SSR but measure solar radiation that is reflected back to space. However there are various models to get SSR value from satellite measurements of radiation [1,9]. These data sets are lacking for the dimming period but some results on the brightening period can be obtained. Results of these studies can be seen in Table 1.3.

As mentioned above, there are also various studies around the world analyzing the SD measurements. SD is a proxy data to analyze SSR so it is important to analyze SD data sets. Sanchez-Lorenzo et al. [11] analyzed spatial and temporal changes in SD and total cloud cover (TCC) on the Iberian Peninsula. SD and TCC have highly negative correlation and they showed this correlation in this study. After removing the effect of TCC on SD values they found negative trends in between 1950s to the early 1980s and positive trends after the early 1980s.

Table 1.1: Trends of SSR values of global and regional sites all around the Earth in dimming period. Table was taken from Wild's study [2].

Table 1. Estimated Linear Changes in Surface Solar Radiation Over the Period of Roughly 1960s to 1980s Based on Surface Observations[a]

Region	Reference	Number of Sites	Period	Absolute Trend ($W\ m^{-2}\ decade^{-1}$)	Relative Trend ($\%\ decade^{-1}$)
		Global Focus			
Global land sites	*Gilgen et al.* [1998]	400	1960–1990	−3.5[b]	−2
Global land sites	*Stanhill and Cohen* [2001]	145	1958–1992	−5.1	−2.7
Global land sites	*Liepert* [2002]	295	1961–1990	−2.3	−1.3
Global urban sites	*Alpert et al.* [2005]	144	1964–1989	−4.1	−2.3[b]
Global rural sites	*Alpert et al.* [2005]	174	1964–1989	−1.6	−0.9[b]
Global remote sites	*Stanhill and Moreshet* [1994]	7	1953–1991	−4.8	−3.3
Global remote sites	*Dutton et al.* [2006]	5	1977–1990	decrease	decrease
		Europe			
Europe	*Ohmura and Lang* [1989]	13	1959–1988	−2.7	−2.0[b]
Europe	*Norris and Wild* [2007]	75	1971–1986	−3.1	−2.3[b]
Zurich (Switzerland)	*Ohmura and Lang* [1989]	1	1960–1980	−10	−7[b]
Baltic	*Russak* [1990]	3	1964–1986	−5.5[b]	−5
Toravere (Estonia)	*Russak* [1990]	1	1955–1986	−2.5[b]	−2.2
Germany	*Liepert et al.* [1994]	8	1964–1990	−6	−4
European part of FSU	*Abakumova et al.* [1996]	diverse	1960–1987	−2.5 to −8[b]	−2 to −6
Moscow	*Abakumova et al.* [1996]	1	1958–1993	−2.3	−2
Turkey	*Aksoy* [1997]	34[c]	1960–1994	−2[b,c]	−1[c]
Israel	*Stanhill and Ianetz* [1997]	2	1954–1994	−8.8	−5
Ireland	*Stanhill* [1998a]	8	1954–1995	−5.2	−5[b]
Iberian Peninsula	*Sanchez-Lorenzo et al.* [2007]	72[c]	1950–1980	−3[c]	−1.5[b,c]
Northern Europe	*Stjern et al.* [2009]	11	1955–2003	−4.3	−3.7
		North America			
United States	*Liepert* [2002]	43	1961–1990	−6	−3
Canada	*Cutforth and Judiesch* [2007]	7	1958–1999	−2.6[b]	−1.7
		Central America			
Wider Caribbean	J. C. Antuna et al. (submitted manuscript 2009)	30	1961–1990	−10	−4.5[b]
		Asia			
Hong Kong	*Stanhill and Kalma* [1995]	1	1958–1992	−18	−10.6
Former Soviet Union	*Abakumova et al.* [1996]	160	1960–1987	−1 to −8	−1 to −7
China	*Che et al.* [2005]	64	1961–2000	−4.5	−3[b]
China	*Liang and Xia* [2005]	42	1960–2000	−4.9[b]	−3.3
China	*Qian et al.* [2007]	85	1955–2000	−3.2	−2.1[b]
China	*Shi et al.* [2008]	84	1957–2000	−3.8[b]	−2.5
China	*Shi et al.* [2008]	84	1961–1989	−7[b]	−4.6
Japan	*Ohmura* [2006]	26	1961–1990	−8	−5[b]
Japan	*Norris and Wild* [2009]	86	1971–1989	−1.3	−0.8[b]
India	*Ramanathan et al.* [2005]	10	1966–1990	−2.9	−1.4[b]
		Africa			
Egypt (Cairo)	*Omran* [2000]	1	1968–1994	−13[b]	−6
South Africa/Namibia	*Power and Mills* [2005]	10	~1960–1990	−5.4	−2.2
Zimbabwe	*Wild et al.* [2005]	3	1965–2000	decrease	decrease
		Oceania			
New Zealand	*Liley* [2009]	4	1954–1990	−4.8[b]	−3
		Polar Regions			
South pole	*Dutton et al.* [1991]	1	1976–1987	decrease	decrease
Arctic	*Stanhill* [1995]	22	1950–1993	−3.6	−4[b]
Antarctica	*Stanhill and Cohen* [1997]	12	1957–1994	−2.8	−2.3[b]

[a]Originally published estimates converted into common units ($W\ m^{-2}\ decade^{-1}$ for absolute changes and $\%\ decade^{-1}$ for relative changes). Studies within individual regions are ordered according to the year of publication.

[b]If not both absolute and relative changes were given in the publications, they were determined from the originally published values and additional information on the absolute magnitude of SSR at the station or region under consideration and flagged with "b".

[c]Derived from sunshine duration data.

Table 1.2: Trend of SSR values of global and regional sites all around the Earth in brightening period. Table was taken from Wild's study [2].

Table 2. Estimated Linear Changes in Surface Solar Radiation Over the Period of Roughly 1980s to 2000s Based on Surface Observations[a]

Region	Reference	Number of Sites	Period	Absolute Trend ($W m^{-2} decade^{-1}$)	Relative Trend (% $decade^{-1}$)
		Global Focus			
Global land sites (GEBA)	*Wild et al.* [2008]	352	1986–2000	2.2	1.2[b]
Global remote sites (BSRN)	*Wild et al.* [2005]	8	1992–2002	6.6[c]	3.6[b,c]
Global remote sites (NOAA/ESRL)	*Dutton et al.* [2006]	5	1990–2000	increase	increase
Global remote sites (BSRN)	*Wild et al.* [2009]	17	1992–2005	5.1[c]	2.8[b,c]
		North America			
Continental United States	*Long et al.* [2009]	7	1995–2007	8	4.4[b]
Oregon	*Riihimaki et al.* [2009]	3	1980–2007	2 to 3	1 to 2
		Europe			
Europe	*Norris and Wild* [2007]	75	1987–2002	1.4	1[b]
Europe	*Wild et al.* [2009]	133	1985–2005	3.3 (2.4[d])	2.5 (1.8[d])
Iberian Peninsula	*Sanchez-Lorenzo et al.* [2007]	72[e]	1980–2000	4[e]	2.2[b,e]
Iberian Peninsula	*Wild et al.* [2009]	11	1985–2005	4.9	2.6[b]
France	*Wild et al.* [2009]	23	1985–2005	3.6	2.4[b]
Switzerland	*Ruckstuhl et al.* [2008]	25	1981–2005	2.6 (1.6[d])	2[b] (1.2[b,d])
Switzerland/Austria	*Wild et al.* [2009]	19	1985–2005	3.7	2.6[b]
North Germany	*Ruckstuhl et al.* [2008]	8	1981–2005	3.3 (2.4[d])	3[b] (2.2[b,d])
Germany	*Wild et al.* [2009]	7	1985–2005	4.6	3.8[b]
Eastern Europe	*Wild et al.* [2009]	23	1985–2005	2.3	1.7[b]
Toravere (Estonia)	*Russak* [2009]	1	1990–2007	increase	increase
Moscow	*Abakumova et al.* [2008]	1	1985–2006	increase	increase
Benelux	*Wild et al.* [2009]	10	1985–2005	4.2	3.7[b]
Great Britain	*Ohmura* [2009]	7	1990–2005	5	4.7[b]
Northern Europe	*Stjern et al.* [2009]	11	1983–2003	2.2[b]	2.1
Scandinavia	*Wild et al.* [2009]	21	1985–2005	1.6	1.6[b]
		Asia			
India	*Padma Kumari et al.* [2007]	12	1984–2001	−8.6	−4
Japan	*Ohmura* [2006]	26	1990–2002	8	5[b]
Japan	*Wild et al.* [2009]	13	1990–2000	7.7	5[b]
Japan	*Norris and Wild* [2009]	86	1990–2002	8.9	5.5[b]
China	*Shi et al.* [2008]	84	1990–2000	2.7[b]	1.8
China	*Norris and Wild* [2009]	23	1990–2002	4.0	2.7[b]
China	*Wild et al.* [2009]	12	1990–2000	5.0	3.3
China	*Wild et al.* [2009]	12	2000–2005	−4.2	−2.8[b]
		Oceania			
Australia	*Wild et al.* [2005]	14	1994–2003	increase	increase
New Zealand	*Liley* [2009]	4	1990–2008	0.5[b]	0.3
		Antarctica			
South pole	*Wild et al.* [2009]	1	1992–2004	4.1	3.1[b]
Georg von Neumayer station	*Wild et al.* [2009]	1	1993–2005	13.4	10.7[b]

[a]Originally published estimates converted into common units ($W m^{-2} decade^{-1}$ for absolute changes and % $decade^{-1}$ for relative changes). Studies within individual regions are ordered according to the year of publication.
[b]If not both absolute and relative changes were given in the publications, they were determined from the originally published values and additional information on the absolute magnitude of SSR at the station or region under consideration and flagged with "[b]".
[c]Enhanced by Pinatubo influence at beginning of records.
[d]Without year 2003.
[e]Derived from sunshine duration data.

Also, Sanchez-Lorenzo et al. [4] analyzed the 79 series of daily or monthly SD data sets which are in 7 countries in Western Europe and these sites represent half of the Europe. The trend results of this study can be seen in Figure 1.4. There is an obvious consistency with the phenomena known as *global dimming and brightening*. Trend line decreases in between 1950s to 1980s and increases after the 1980s.

Table 1.3. Results of trend values of satellite derived data for various studies in brightening period. Table was taken from Wild's study [2].

Table 3. Estimated Linear Changes in Surface Solar Radiation Over the Period of Roughly 1980s to 2000s in Satellite-Derived Products[a]

Region	Reference	Period	Absolute Trend ($W\ m^{-2}\ decade^{-1}$)	Relative Trend (% $decade^{-1}$)
Global	*Pinker et al.* [2005]	1983–2001	1.6	0.9[b]
Global land	*Pinker et al.* [2005]	1983–2001	−0.5	−0.3[b]
Global ocean	*Pinker et al.* [2005]	1983–2001	2.4	1.3[b]
Global	*Hatzianastassiou et al.* [2005]	1984–2000	2.4	1.3[b]
Global land	*Hatzianastassiou et al.* [2005][c]	1984–2000	1.8	1.0[b]
Global ocean	*Hatzianastassiou et al.* [2005][c]	1984–2000	2.7	1.5[b]
Global	N. Hatzianastassiou et al. (submitted manuscript, 2009)	1984–2001	3.5	1.9[b]
Global land	N. Hatzianastassiou et al. (submitted manuscript, 2009)	1984–2001	3.7	2.1[b]
Global ocean	N. Hatzianastassiou et al. (submitted manuscript, 2009)	1984–2001	3.6	2.0[b]
Global	*Hinkelman et al.* [2009]	1991–1999	3.2	1.8[b]
Global	*Hinkelman et al.* [2009]	1983–2004	0.25	0.1[b]

[a]Units $W\ m^{-2}\ decade^{-1}$ for absolute changes and % $decade^{-1}$ for relative changes.
[b]If not both absolute and relative changes were given in the publications, they were determined from the originally published values and additional information on the absolute magnitude of SSR at the station or region under consideration and flagged with "[b]".
[c]Personal communication, based on data set described in reference.

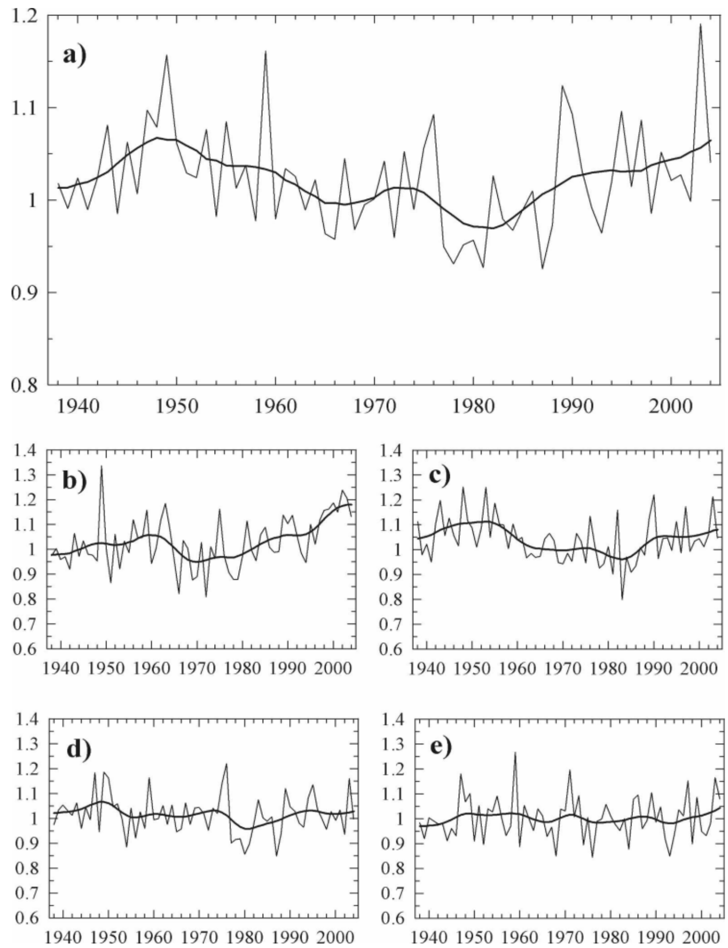

Figure 1.4. SD variations for Western Europe. Thin line represents the SD variations and thick line represents the 11-yr window 3-yr-σ Gaussian low-pass filter. Figure a is for annual averages, b for summer averages, c for spring averages, d for summer averages and e for autumn averages. Figure was taken from Sanchez-Lorenzo's et al. study [4].

Stanhill and Cohen [12] used SD data between 1890 to 2002 in Japan as proxy data for SSR . They identified 0.08 Wm^{-2} average increases in solar radiation in 20th century but this increase has no certain known trends. In addition to this, Stanhill and Cohen [13] used SD values of 106 Weather Bureau stations in the USA as proxy of SSR. About 70 of these stations have SD data sets between 1891 and 1987. They reached the result that SD database shows little evidence for a significant trend in 20th century.

Liley [14] used SD database at 207 sites around New Zealand and the South Pacific. Some of these records start at 1905. There is decreasing trend between 1950s and 1990s and increasing trend after the 1990s.

Kaiser and Qian [15] analyzed the SD data of 200 stations in China. It is determined by Kaiser and Qian that most of the stations have decreasing trend between 1954 and 1998. And trend values are approximately -2 to -3 percent per decade. Over western and northern China few stations have increasing trend.

1.4 Dimming and Brightening in Turkey

There are also some evidences on the *global dimming and brightening* about Turkey.

Aksoy [8] studied with the SD for 34 stations in Turkey between 1960-1994. These stations are given in Figure 1.5. These data sets were obtained from TSMS. In this study SSR values are calculated by using SD values. Aksoy developed and used a modified version of equation of Ögelman et al [16] for monthly averages. This equation is

$$\langle\frac{H}{H_0}\rangle = 0.148 + 0.668\,\langle\frac{n}{N}\rangle - 0.079\,\langle\frac{n}{N}\rangle^2 \qquad (1.4)$$

In equation 1.4, H is the SSR value and H_0 is the extraterrestrial solar radiation. n is the measured value of SD and N is the length of the day.

These estimations of SSR data sets were analyzed by Aksoy and the results of the trend analyses can be seen in Table 1.4 and Table 1.5.

As can be seen in Table 1.4 most of the station's SSR value has negative trend in yearly, autumn and summer averages and most of station have no trend in winter and summer averages. And numerical values of the trends are given in Table 1.5. Average trend between 1960 to1994 is -3.4 %.

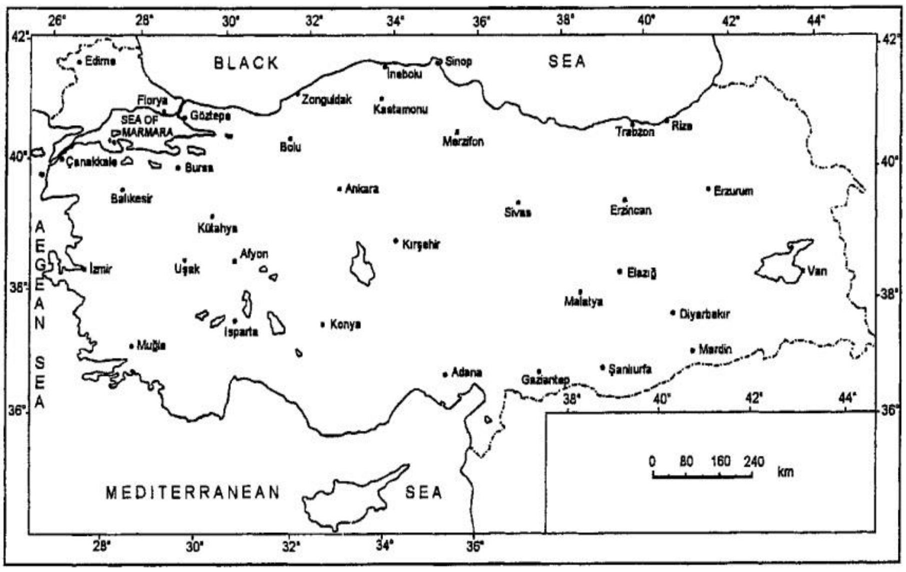

Figure 1.5. Distribution of the stations used in Aksoy's (1997) study [8].

Table 1.4. Trend results of Aksoy's (1997) study [8].

Table 1. *Results of the Trend Analysis at the 5 per Cent Significance Level of Global Radiation at 34 Stations in Turkey for the Period 1960–1994.* (−) Significant negative trend; (+) significant positive trend; (0) no significant trend

Stations	Winter	Spring	Summer	Autumn	Annual
Adana	0	−	−	−	−
Afyon	−	−	−	−	−
Ankara	0	0	−	−	−
Balikesir	0	0	−	−	−
Bolu	−	0	−	−	−
Bursa	0	0	−	−	−
Çanakkale	0	−	−	−	−
Diyarbakir	0	0	−	−	0
Edirne	0	−	−	−	−
Elaziğ	0	0	−	−	0
Erzincan	−	0	−	−	−
Erzurum	−	−	−	−	−
Florya	0	0	−	−	−
Gaziantep	0	−	−	−	−
Göztepe	−	−	−	−	−
Inebolu	0	0	−	−	−
Isparta	0	0	0	0	0
Izmir	0	0	0	0	0
Kastamonu	0	0	−	−	−
Kirşehir	0	0	0	0	0
Konya	−	0	−	−	−
Kütahya	0	0	0	0	0
Malatya	0	0	−	−	0
Mardin	0	+	+	0	+
Merzifon	0	0	−	−	−
Muğla	+	0	−	0	−
Rize	−	0	0	−	−
Sinop	0	0	−	−	−
Sivas	−	0	0	0	−
Şanliurfa	0	−	−	−	−
Trabzon	−	−	−	−	−
Uşak	0	0	−	0	0
Van	0	0	−	0	−
Zonguldak	0	0	−	−	0

Table 1.5. Trend values percentage for each station in Aksoy's (1997) study [8]. A and B are not the coefficients of Angström-Prescott relation. They are the coefficients of the trend line.

Table 2. *Linear Change of Global Solar Radiation at 34 Stations in Turkey Between the Years 1968 and 1986.* A and B, regression coefficients; R, relative change in radiation; (*) significant changes at the 5 per cent level

Stations	A	B	R(%)
Adana	17.0	−0.0531	−5.8*
Afyon	15.6	−0.0393	−4.6*
Ankara	15.4	−0.0319	−3.80*
Balikesir	15.2	−0.0306	−3.7*
Bolu	13.4	−0.0362	−5.0*
Bursa	14.5	−0.0311	−3.9*
Çanakkale	15.8	−0.0291	−3.4*
Diyarbakir	16.6	−0.0136	−1.5
Edirne	14.4	−0.0432	−5.5*
Elaziğ	15.8	−0.0117	−1.3
Erzincan	15.2	−0.0425	−5.2*
Erzurum	15.4	−0.0387	−4.6*
Florya	14.6	−0.0339	−4.3*
Gaziantep	17.7	−0.0819	−8.7*
Göztepe	14.5	−0.0541	−7.0*
Inebolu	13.1	−0.0310	−4.4*
Isparta	15.8	−0.0034	−0.4
Izmir	16.5	−0.0083	−0.9
Kastamonu	13.8	−0.0334	−4.5*
Kirşehir	15.4	−0.0068	−0.8
Konya	16.1	−0.0294	−3.3*
Kütahya	13.4	−0.0072	−1.0
Malatya	16.2	−0.0141	−1.6
Mardin	15.9	+0.0273	+3.0*
Merzifon	14.4	−0.0285	−3.6*
Muğla	16.3	−0.0182	−2.0*
Rize	10.8	−0.0170	−2.9*
Sinop	13.3	−0.0412	−5.7*
Sivas	14.9	−0.0191	−2.3*
Şanliurfa	17.8	−0.0424	−4.4*
Trabzon	11.8	−0.0497	−7.9*
Uşak	16.1	−0.0123	−1.4
Van	16.6	−0.0251	−2.8*
Zonguldak	13.2	−0.0137	−1.9
Average	15.1	−0.0278	−3.4

Another study of Aksoy [17] examines the satellite-based radiation data obtained from National Aeronautics and Space Administration (NASA) and compares these data with reliable ground observations. In this study NASA Surface Meteorology and Solar Energy (SSE) dataset obtained for 85 grid cells in between July 1983 to December 2005. To compare with satellite derived data the new network of 20 stations of pyranometers and pyrheliometers were taken from TSMS. However some of the stations are not well located to represent the typical climates of Turkey, some were founded at inappropriate locations and some have communication and software problems. Due to these reasons only 8 stations are used for quality-control of data sets. Quality-control of these 8 stations was made by using SD data. After this quality-control Aksoy has found that 5 of the 8 stations are reliable. Grid cells and 5 stations are given in Figure 1.6. Comparison of satellite derived data with surface based measurements gives low mean relative error of about 4%.

Also trend analysis of the satellite derived data was made by Aksoy by using the Mann–Kendall rank correlation test. Results of these trend tests are given in Table 1.6. In this table, *N* represents grid cell number and *u(t)* represents test statistics. In this table it can be seen that most of the grid cells have significant positive trend. This result supports the event of the *global dimming and brightening*.

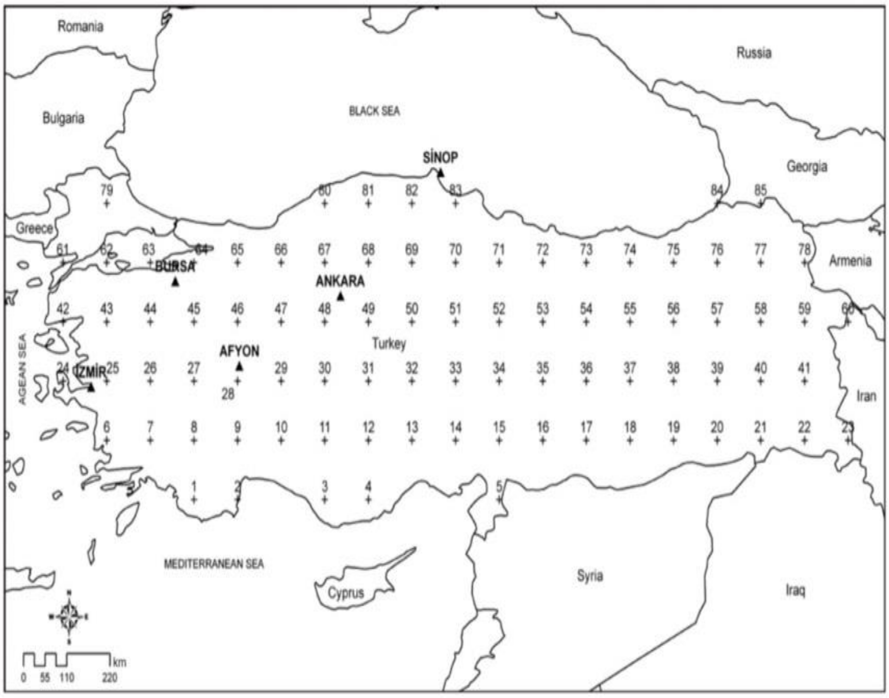

Figure 1.6. 85 grid cells and new network radiation stations for Turkey. Figure was taken from Aksoy's (2010) study [17].

Table 1.6. Results of Mann–Kendall rank correlation test of Aksoy’s (2010) study [17] .

	Centre of cell					Centre of cell			
N	Latitude (°)	Longitude (°)	$u(t)$	YI	N	Latitude (°)	Longitude (°)	$u(t)$	YI
1	36.5	29.5	3.83**	1995	44	39.5	28.5	1.86	–
2	36.5	30.5	2.14*	1991	45	39.5	29.5	0.79	–
3	36.5	32.5	4.54**	1997	46	39.5	30.5	1.92	–
4	36.5	33.5	4.15**	1997	47	39.5	31.5	1.49	–
5	36.5	36.5	1.10	–	48	39.5	32.5	2.45*	1997
6	37.5	27.5	0.59	–	49	39.5	33.5	2.45*	1997
7	37.5	28.5	3.58**	1995	50	39.5	34.5	2.48*	1992
8	37.5	29.5	1.92	–	51	39.5	35.5	2.51*	1991
9	37.5	30.5	3.07**	1989	52	39.5	36.5	1.95	–
10	37.5	31.5	2.90**	1992	53	39.5	37.5	2.68**	1991
11	37.5	32.5	2.26*	1998	54	39.5	38.5	2.23*	1997
12	37.5	33.5	3.05**	1997	55	39.5	39.5	3.19**	1997
13	37.5	34.5	0.37	–	56	39.5	40.5	3.47**	1996
14	37.5	35.5	3.16**	1999	57	39.5	41.5	1.58	–
15	37.5	36.5	2.88**	1997	58	39.5	42.5	0.68	–
16	37.5	37.5	3.52**	1997	59	39.5	43.5	−0.93	–
17	37.5	38.5	3.07**	1997	60	39.5	44.5	−1.47	–
18	37.5	39.5	3.44**	1996	61	40.5	26.5	3.27**	1992
19	37.5	40.5	3.19**	1996	62	40.5	27.5	2.23*	1989
20	37.5	41.5	3.36**	1996	63	40.5	28.5	0.03	–
21	37.5	42.5	3.47**	1996	64	40.5	29.5	1.41	–
22	37.5	43.5	3.81**	1995	65	40.5	30.5	3.10**	1997
23	37.5	44.5	4.37**	1994	66	40.5	31.5	3.21**	1998
24	38.5	26.5	2.43*	1995	67	40.5	32.5	2.20*	1997
25	38.5	27.5	2.71**	1991	68	40.5	33.5	3.44**	1997
26	38.5	28.5	2.31*	1991	69	40.5	34.5	4.00**	1997
27	38.5	29.5	3.10**	1991	70	40.5	35.5	2.96**	1997
28	38.5	30.5	2.31*	1991	71	40.5	36.5	3.38**	1995
29	38.5	31.5	2.74**	1991	72	40.5	37.5	2.74**	1996
30	38.5	32.5	2.85**	1996	73	40.5	38.5	3.55**	1994
31	38.5	33.5	3.38**	1997	74	40.5	39.5	2.45*	1992
32	38.5	34.5	2.37*	1996	75	40.5	40.5	1.41	–
33	38.5	35.5	1.92	–	76	40.5	41.5	2.45*	1992
34	38.5	36.5	2.00*	1996	77	40.5	42.5	1.13	–
35	38.5	37.5	2.82**	1997	78	40.5	43.5	2.11*	1991
36	38.5	38.5	2.26*	1991	79	41.5	27.5	1.72	–
37	38.5	39.5	3.05**	1996	80	41.5	32.5	−0.31	–
38	38.5	40.5	2.79**	1995	81	41.5	33.5	−1.33	–
39	38.5	41.5	3.16**	1996	82	41.5	34.5	−1.33	–
40	38.5	42.5	2.68**	1994	83	41.5	35.5	2.79**	1998
41	38.5	43.5	3.44**	1995	84	41.5	41.5	0.28	–
42	39.5	26.5	3.38**	1992	85	41.5	42.5	2.14*	1996
43	39.5	27.5	2.71**	1992					

Notes: N is the grid cell number, $u(t)$ is the Mann–Kendall test statistic with its significance at the 0.05 level (*) and 0.01 level (**) and YI intercept year means the beginning of the trend in the time series.

CHAPTER 2

DATA, STATISTICAL METHODS and STATISTICAL APPLICATIONS

2.1 Introduction

Sunshine duration (SD) has been defined in introduction chapter and relation between solar surface radiation (SSR) and SD has been explained. In this chapter, recent SD data of Turkey, statistical methods, analysis of this data by these statistical method and some interpretations are given. The analyses include solving the missing value problem of data sets, determining which of the data sets are homogenous and investigation of trends.

SD data has been measured since the years 1930s by TSMS in Turkey. But the data before 1970 is not given to the researchers due to the lack of quality-control. (This information was obtained from the Meteorological Data Processing Department of TSMS.). Daily data set of 192 stations was taken from TSMS and these stations are distributed uniformly through Turkey.

2.2 Missing Value Problem

The data set was in one txt file so it was needed to split the data station by station. Each station's data set is investigated one by one while splitting them. After this investigation it is observed that 73 station's data set has missing values less than 6%. Some other stations have around 10% of missing values and they are eliminated from the analysis. Therefore, we have chosen 6% as the threshold for imputation, and used them for the trend analysis. Also 64 of these 73 remaining station have less than 3% missing values.

Case deletion or substitution of the mean value can be safely used in order to solve the missing value problem when the ratio of the missing value is less than 5% of the data set [18]. Most of the station dataset obey this rule. However some of them are at the boundary (4 sites) so a more complicated statistical method, Expectation Maximization (EM) algorithm, was used to impute missing values.

There are three types of missingness. First one is *missing completely at random* (MCAR) case. If the missingness does not depend on the observed and missing values, this type of missingness is called as MCAR. (For our case for example if the person in charge do not replace the strip paper for that day, this is an MCAR missing value) This does not mean that patterns of missing values are random. Randomness is related with the mechanism of the missing values. Second one is *missing at random* (MAR) data. If missing values depend on an observed value however it does not depend itself such kind of missingness is called as MAR. (For example in our case, one of the person in charge do not record the data from time to time.)Third one is *not missing at random* (NMAR). If the missingness depends on the missing values it is called as NMAR [19] (In our case, missing observations in a specified interval might be due to exclusion of a certain classification of the data. However, in our data such missingness should not be encountered.)

MAR data may be ambiguous. So it can be clarified by giving an explanatory case. Howell [20], in his web site, gives a good example for MAR data: "…people who are depressed might be less inclined to report their income, and thus reported income will be related to depression. Depressed people might also have a lower income in general, and thus when we have a high rate of missing data among depressed individuals, the existing mean income might be lower than it would be without missing data. However, if, within depressed patients the probability of reported income was unrelated to income level, then the data would be considered MAR…"

It is assumed that SD data is MCAR, since missingness is related with instrumentation and coding problems, weather conditions etc.
To impute the missing values in data sets IMB SPSS 18 package program were used. SPSS 18 [21] manual summarize that for MCAR data listwise, pairwise, regression and EM methods can be used for missingness problem. So, one of these methods, the EM method, has been chosen.

EM algorithm assumes normal distribution [18]. However it is argued that sunshine duration data cannot be normally distributed [22]. Schafer [18] explains that EM method can be also used in nonnormal cases: "If some variables in a dataset are clearly nonnormal (e.g. discrete) but are completely observed, then the multivariate normal model may still be used for inference provided that (a) it is plausible to model the incomplete variables as conditionally normal given a linear function of the complete ones, and (b) the parameters of inferential interest pertain only to this conditional distribution" [18]. We used the multivariate EM algorithm method to impute the missing values. That is, while imputing the missing values both the data set under consideration and the other data sets are comparatively used.

Imputation results are given in Table 2.1 after applying EM method by using SPSS 18. Table 2.1 shows the percentages and counts of missing values and extremes in observed values.

2.3 Homogeneity of Data Sets

Second step is determining whether each data set is homogenous or not, after the imputation of missing values. Homogeneity is defined as "A homogeneous climate dataset is one in which all the fluctuations contained in its time series reflect the actual variability and change of the represented climate element" [23].

Meteorological data sets may have some non-meteorological or non-climatological errors. These can be originated by the instrumentation, coding, processing. These are changes in geographical location; local land use and land cover; instrument types, exposure, mounting and sheltering; observing practices; calculations, codes and units; and historical and political events. Some of these effects cause abrupt change and some cause gradual change. For instance replacing the instrumentation with the new one may cause abrupt change while the urbanization around the station causes gradual change [23].

Table 2.1. Details of missing value problem.

code and name	number of value	Mean	Std. Deviation	Missing		No. of Extremes	
				Count	Percent	Low	High
17022-zonguldak	14996	5,663	4,5825	160	1,1	0	0
17024-inebolu	15094	5,544	4,5369	62	0,4	0	0
17026-sinop	14878	5,482	4,0690	278	1,8	0	1
17030-samsun	14496	5,351	4,1391	660	4,4	0	0
17033-ordu	15065	4,522	3,8664	91	0,6	0	89
17040-rize	14984	4,150	4,0058	172	1,1	0	496
17042-hopa	14757	4,431	4,1264	399	2,6	0	199
17050-edirne	14679	6,236	4,3512	477	3,1	0	0
17066-kocaeli	14860	5,532	4,1272	296	2,0	0	0
17070-bolu	14968	5,440	4,0631	188	1,2	0	82
17074-kastamonu	14877	5,863	4,1984	279	1,8	0	0
17080-çankırı	15058	6,212	4,1086	98	0,6	0	0
17083-merzifon	14977	6,422	4,2341	179	1,2	0	0
17088-gümüşhane	14831	5,854	4,2244	325	2,1	0	0
17090-sivas	15101	6,824	4,5997	55	0,4	0	0
17094-erzincan	15068	6,547	4,0948	88	0,6	0	0
17096-erzurum	14215	6,702	4,1409	941	6,2	0	0
17097-kars	14787	6,472	3,9858	369	2,4	0	27
17100-ığdır	14874	6,452	3,9331	282	1,9	0	0
17110-gökçeada	14994	7,390	4,6742	162	1,1	0	0
17112-çanakkale	14969	7,214	4,3911	187	1,2	0	0
17114-bandırma	15151	6,552	4,4586	5	0,0	0	0
17116-bursa	14880	6,182	4,3680	276	1,8	0	0
17130-ankara	14938	6,863	4,3347	218	1,4	0	0
17140-yozgat	15144	6,906	4,2077	12	0,1	0	0
17155-kütahya	15063	5,798	3,9441	93	0,6	0	0
17160-kırşehir	15033	7,317	4,3255	123	0,8	0	0
17172-van	14952	8,019	4,0673	204	1,3	0	0
17175-ayvalık	15091	7,709	4,2908	65	0,4	0	0
17180-dikili	15090	8,120	4,2203	66	0,4	0	0
17186-manisa	14899	6,851	4,2442	257	1,7	0	0
17190-afyon	14943	6,724	4,2036	213	1,4	0	0
17191-cihanbeyli	15023	7,566	4,2509	133	0,9	0	0
17192-aksaray	15075	7,539	4,4011	81	0,5	0	0
17193-nevşehir	15143	7,206	4,4207	13	0,1	0	0
17196-kayseri	15113	6,860	4,3083	43	0,3	0	0
17199-malatya	14845	7,707	4,3987	311	2,1	0	0
17201-elazığ	15069	7,458	4,5341	87	0,6	0	0
17204-muş	14880	7,299	4,8171	276	1,8	0	0
17210-siirt	15110	7,625	4,4025	46	0,3	0	0
17220-izmir	15125	7,980	4,1118	31	0,2	0	0
17232-kuşadası	14919	8,117	3,9886	237	1,6	757	0
17237-denizli	15109	7,427	4,1237	47	0,3	0	0
17238-burdur	15138	7,420	4,0139	18	0,1	0	0
17240-ısparta	15133	7,492	4,1186	23	0,2	0	0
17246-karaman	14909	8,102	4,4509	247	1,6	0	0
17250-niğde	15151	7,625	4,1979	5	0,0	0	0
17261-antep	15009	7,232	3,7001	147	1,0	0	0
17265-adıyaman	15002	8,038	4,3450	154	1,0	0	0
17270-urfa	15129	8,000	4,0545	27	0,2	0	0
17275-mardin	14863	8,219	4,3178	293	1,9	0	0
17280-diyarbakır	14206	7,854	4,3160	950	6,3	0	0
17285-hakkari	14806	7,836	4,2714	350	2,3	0	2
17292-muğla	14960	7,251	3,8694	196	1,3	0	0
17294-dalaman	15139	8,211	3,7141	17	0,1	1072	0
17300-antalya meydan	14520	8,382	3,7757	636	4,2	1131	0
17320-anamur	15129	8,124	3,6617	27	0,2	1144	0
17351-adana	14929	7,444	3,5724	227	1,5	926	0
17370-iskenderun	15107	7,262	3,6022	49	0,3	612	0
17375-finike	15128	8,283	3,7085	28	0,2	1020	0
17606bozkurt kastamonu	14873	5,377	4,3129	283	1,9	0	0
17610-şile	14691	5,856	4,4033	465	3,1	0	6
17624-ünye	14737	5,192	4,2546	419	2,8	0	8
17632-ipsalaedirne	14633	6,493	4,3667	523	3,5	0	0
17636-florya	14898	6,616	4,4741	258	1,7	0	0
17768-çemişgezek	14299	6,890	4,0746	857	5,7	0	0
17776-solhan bingöl	14780	7,259	4,2528	376	2,5	0	0
17780-malazgirt muş	14729	6,580	4,3653	427	2,8	0	0
17804-keban elazığ	15050	7,331	4,3812	106	0,7	0	0
17866-göksun maraş	14902	7,660	4,3737	254	1,7	0	0
17912-siverek urfa	14750	7,842	4,2243	406	2,7	0	0
17950-cizre	14351	8,331	4,2357	805	5,3	0	0
17966-birecik urfa	15061	7,846	4,0229	95	0,6	0	0

Sneyers [24] proposed the nonparametric Kruskal-Wallis and Wald-Wolfowitz runs tests. In this study both of the tests were used. After applying these tests a subjective assessment also was done.

Determining the homogeneity of a data set includes two steps: metadata analysis (station archives) and the statistical methods. Firstly, the metadata of the stations must be investigated [23]. Station archives contain location and relocation information of the station, change of the instruments, calibration of the instruments etc. One can investigate the details of the past of all stations so can have an idea about the homogeneity of the data set of that station. However the metadata tables of the TSMS are not adequate to make a good assessment. Therefore investigating the station archives was skipped.

Secondly statistical methods must be used. The criterion for choosing the statistical method to detect inhomogeneities is the probability distribution of the data set. For normal distribution the parametric methods work well but if there is no assumption for the probability distribution non-parametric methods work well [23].

Kruskal Wallis (K-W) test is a non-parametric test. The algorithm of the test has been summarized in Anderson et al. [25] and is explained below by using the İnebolu station (station code is 17024) by using annual averages. First step of the test is determining the rank of each year. If there are same values in different years, average value of the ranks is substituted. Then divide the data set in sub groups with respect to time sequence. Each sub group must have at least 5 elements. These two steps can be seen in Table 2.2. Sum of ranks of each sub group is R_1, R_2… R_8. The Table 2.2 has 8 groups and 8 sum of ranks.

Test's hypothesizes are given below.

Null hypothesis (denoted as h_0): all groups are originated from same distribution.

Alternative hypothesis (denoted as h_1): at least one group is not originated from the same distribution.

If the null hypothesis is rejected then it said to that data set is not homogeneous.

The test statistic (K) of K-W test is

$$K = \frac{12}{n(n+1)} \sum_{i=1}^{k} \frac{R_i}{n_i} - 3(n+1) \qquad (2.1)$$

Where, k: number of groups; n_i: number of data in each group R_i; n: total number of data and R_i: sum of the ranks for the i^{th} group.

Table 2.2. Determining ranks of each year for İnebolu station.

group 1	value	rank	group 2	value	rank	group 3	value	rank	group 4	value	rank
1970	6,4	41	1975	5,7	27,5	1980	5,5	18	1985	5,2	8,5
1971	5,7	27,5	1976	5,5	18	1981	5,2	8,5	1986	5,2	8,5
1972	5,8	34	1977	5,3	12	1982	5,8	34	1987	5,1	3,5
1973	5,5	18	1978	5,3	12	1983	5,3	12	1988	4,8	2
1974	5,8	34	1979	5,6	22	1984	5,7	27,5	1989	5,6	22
		sum:154,5			sum: 91,5			sum: 100			sum: 44,5
group 5	value	rank	group 6	value	rank	group 7	value	rank	group 8	value	rank
1990	6,1	39	1995	5,7	27,5	2000	5,7	27,5	2005	5,2	8,5
1991	4,7	1	1996	5,1	5,5	2001	5,6	22	2006	5,5	18
1992	5,1	5,5	1997	5,1	3,5	2002	5,8	36	2007	6,3	40
1993	5,5	18	1998	5,4	14,5	2003	5,7	27,5	2008	6	37,5
1994	6	37,5	1999	5,7	27,5	2004	5,7	27,5	2009	5,7	27,5
		sum: 101			sum: 78,5			sum: 140,5	2010	5,4	14,5
											sum: 146

K-W test claims that the probability distribution of the *K* is approximately χ^2 distribution for *k-1* degrees of freedom. It usually advised to use *α=0.05* level of significance. This level of significance corresponds to a critical *K* value (K_c). K_c is 14.067 for 7 degrees of freedom. If *K* value of a station is smaller than the critical value then it is homogenous. Otherwise it is not. *K* value for the İnebolu is 13.176. So it is homogenous.

Another nonparametric test is Wald-Wolfowitz runs test for randomness. This test determines whether the data set is random or not with respect to the median or average. If the data set is not random it said to be not homogenous. The algorithm has been summarized from Bradley's book [26].

A run is defined as a series of values above or below the mean (or median) of the data set. Test statistics determines the randomness by using these runs. Hypothesis of this test are given below.

Null hypothesis (h_0): the sequence was produced in a random manner.
Alternative hypothesis (h_1): the sequence was not produced in random manner.

Test statistics (z) is

$$z = \frac{R-R'}{s} \qquad (2.2)$$

Where R: observed number of runs and R': expected number of runs.

$$R' = \frac{2nm}{n+m} + 1 \qquad (2.3)$$

$$s = \sqrt{\frac{2nm(2nm-n-m)}{(n+m)^2(n+m-1)}} \qquad (2.4)$$

Where, *n* and *m*: number of negative (below the mean) and positive (above the mean) values.
If *n>10* and *m>10* then the test statistics can be compared to the standard normal table. In this study *m=20* and *n=21* or vice versa.

By using the level of significance as *α=0,05* the acceptable range of the *Z* is $-1{,}96 \le z \le 1{,}96$.
Results of two nonparametric tests are summarized in Table 2.3.

Table 2.3 shows the station which passes only the K-W test, the runs test and both of the tests. Distinct results have been arisen out for two tests. So there must be criteria to determine which stations are homogenous and which are not.

Table 2.3. Results of homogeneity tests. ‘1’ represents passing the test and ‘0’ represents not passing the test.

code	station	K-W	K value	runs	Z value	missingness %
17022	zonguldak	0	18,913	0	-2,212	1,1
17024	inebolu	1	13,176	1	-0,946	0,4
17026	sinop	0	22,594	0	-2,212	1,8
17030	samsun	0	25,965	0	-4,744	4,4
17033	ordu	0	16,805	1	0,004	0,6
17040	rize	0	18,108	1	-0,946	1,1
17042	hopa	0	15,075	1	-1,262	2,6
17050	edirne	1	13,956	0	-2,212	3,1
17066	kocaeli	0	16,208	0	-2,212	2
17070	bolu	0	23,376	0	-2,845	1,2
17074	kastamonu	0	17,515	1	-1,579	1,8
17080	çankırı	1	6,93	1	-1,895	0,6
17083	merzifon amasya	0	14,929	1	-1,579	1,2
17088	gümüşhane	0	28,215	0	-4,111	2,1
17090	sivas	0	16,502	1	-1,895	0,4
17094	erzincan	0	29,499	0	-3,478	0,6
17096	erzurum	0	26,717	0	-2,845	6,2
17097	kars	1	9,135	0	-2,212	2,4
17100	ığdır	1	14,057	0	-2,212	1,9
17110	gökçeada	1	8,268	1	-0,313	1,1
17112	çanakkale	0	18,773	0	-2,845	1,2
17114	bandırma	0	19,882	1	-0,946	0
17116	bursa	0	21,656	0	-2,212	1,8
17130	ankara	0	14,282	1	-0,946	1,4
17140	yozgat	0	21,327	0	-3,161	0,1
17155	kütahya	0	16,326	0	-2,528	0,6
17160	kırşehir	1	12,562	1	-0,946	0,8
17172	van	0	29,851	0	-2,845	1,3
17175	ayvalık	0	22,491	0	-2,845	0,4
17180	dikili	1	12,646	0	-2,212	0,4
17186	manisa	0	22,753	0	-2,845	1,7
17190	afyon	0	19,139	0	-2,212	1,4
17191	cihanbeyli	0	27,23	0	-2,845	0,9
17192	aksaray	1	12,966	1	-1,579	0,5
17193	nevşehir	0	14,472	1	-1,262	0,1
17196	kayseri	0	23,638	0	-2,528	0,3
17199	malatya	1	6,634	1	-0,946	2,1
17201	elazığ	1	11,634	1	-0,313	0,6
17204	muş	0	19,118	0	-2,212	1,8
17210	siirt	0	14,564	0	-2,212	0,3
17220	izmir	1	10,4	1	-1,579	0,2
17232	kuşadası	0	20,198	0	-2,845	1,6
17237	denizli	0	20,597	0	-2,845	0,3
17238	burdur	0	14,865	1	-0,946	0,1
17240	ısparta	0	20,524	0	-2,845	0,2
17246	karaman	1	12,297	1	-0,629	1,6
17250	niğde	1	11,922	1	-1,579	0
17261	antep	0	28,015	0	-4,111	1
17265	adıyaman	0	18,614	1	-0,313	1
17270	urfa	0	22,271	0	-2,212	0,2
17275	mardin	1	7,096	1	-1,895	1,9
17280	diyarbakır	0	17,324	0	-2,845	6,3
17285	hakkari	1	9,725	1	-1,579	2,3
17292	muğla	0	31,109	0	-3,478	1,3
17294	dalaman	0	26,015	0	-2,845	0,1
17300	antalya meydan	0	22,113	0	-2,528	4,2
17320	anamur	0	27,784	0	-2,845	0,2
17351	adana	0	18,05	1	-0,313	1,5
17370	iskenderun	1	13,468	1	0,637	0,3
17375	finike	0	18,006	1	-1,579	0,2
17606	bozkurt kastamonu	0	22,905	0	-2,212	1,9
17610	şile	1	9,333	1	-1,262	3,1
17624	ünye	0	20,346	1	-0,946	2,8
17632	ipsala edirne	1	8,094	1	0,004	3,5
17636	florya	0	15,984	0	-2,212	1,7
17768	çemişgezek	1	12,547	1	-0,313	5,7
17776	solhan bingöl	1	12,003	1	-1,579	2,5
17780	malazgirt muş	0	32,318	0	-4,744	2,8
17804	keban elazığ	1	6,012	1	-0,946	0,7
17866	göksun kmaraş	1	13,552	1	-1,579	1,7
17912	siverek	1	13,407	1	-0,946	2,7
17950	cizre	0	23,225	0	-4,744	5,3
17966	birecik urfa	0	19,045	1	-0,313	0,6

K-W test gives the result that a data set is not homogenous when the data set has only increasing or decreasing trend. However it cannot be a true handling for our case. A station's data set may have an increasing or decreasing trend between the years 1970 and 2010. In Figure 2.1 this case can be seen. Trend is decreasing between 1970 and 2010. K-W is not a good test for such cases. Also, if there is an unexpected jump in the data set, K-W test is again not a good choice. In Figure 2.2, a jump for the year 1987 can be observed. As shown in Table 2.3, Bandırma and Ordu have small Z values. This means that the data set is random but at least one sub group is different than the others. So these can be realistic data sets.

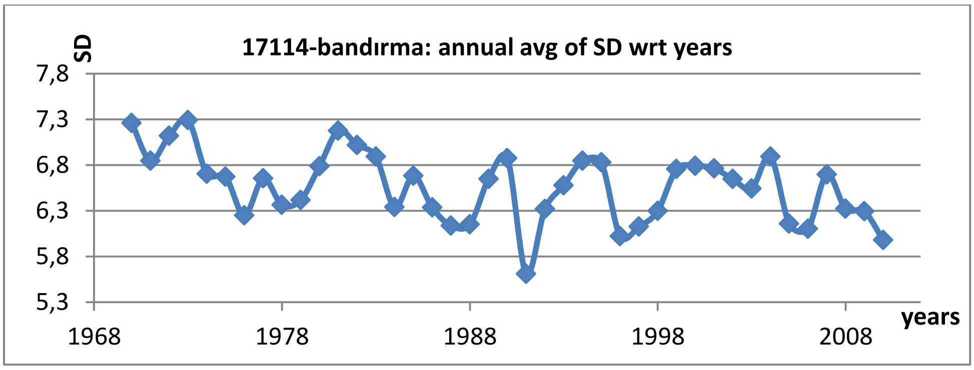

Figure 2.1. Annual averages of SD for Bandırma. Continuously decreasing case.

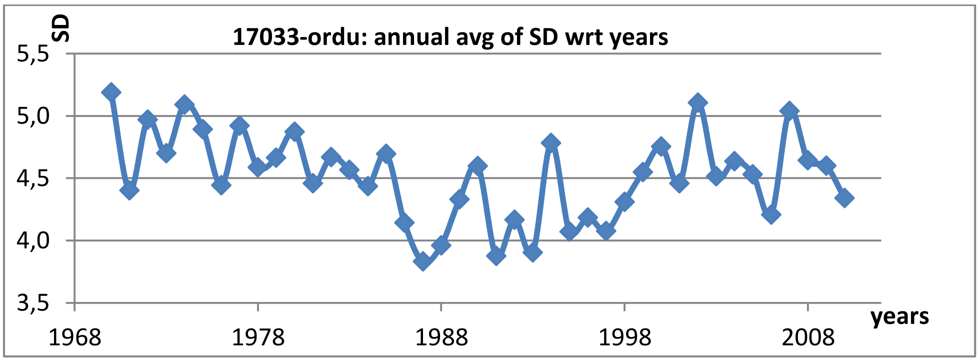

Figure 2.2. Annual averages of the SD of Ordu. Jumping data case.

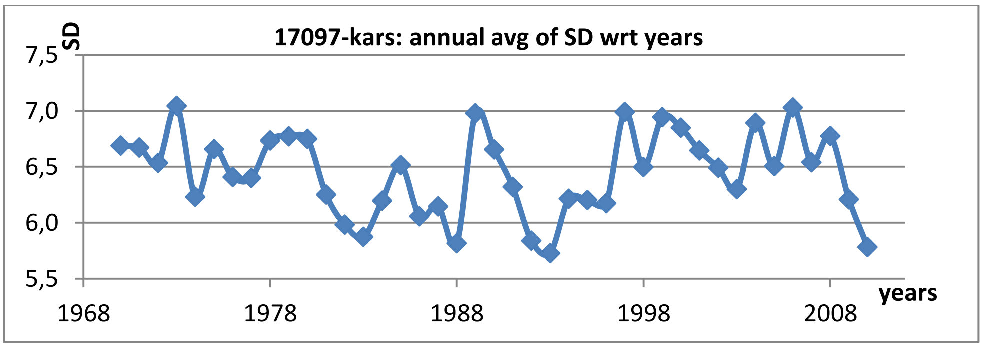

Figure 2.3. Annual averages of the SD of Kars. Long series of data above or below the mean.

On the other hand runs test is not adequate for the cases that can be seen in Figure 2.3 (Kars station). Kars station has large series of data above or below the mean. In runs test's algorithm first step is defining the runs. A run is a series of data which is above or below the mean. The test statistics (*Z*) becomes greater as the number of the runs decreases. And large *Z* value means that the station is not homogenous. Kars station's data set has large series of values above or below the mean. This case decreases the number of runs. In other words the number of runs is not adequate to pass the runs test. However the data set is a realistic data set because it passes the K-W test and long series of data above and below the average may occur for SD data. So the runs test cannot be preferable for these cases.

Therefore, due to the reasons given above further considerations are needed for the stations which do not pass both of the homogeneity tests. For this types of stations graphs of them were plotted and investigated in detail. By using these graphs and values of tests statistics the homogenous stations have been determined. The stations which are assessed as homogenous are located in a map in Figure 2.4 and also given in Table 2.4 (totally 36 stations).

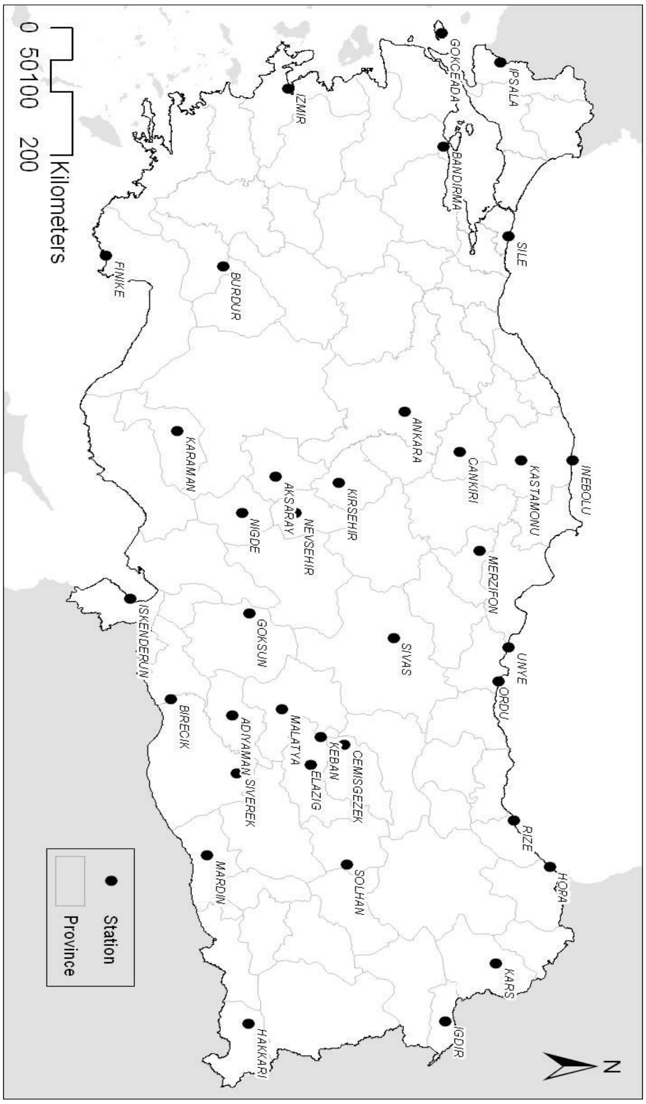

Figure 2.4. The stations determined as homogenous.

Table 2.4. The stations determined as homogenous.

station code	name of station	K value	Z value	Percent of missingness
17024	inebolu	13,176	-0,946	0,4
17033	ordu	16,805	0,004	0,6
17040	rize	18,108	-0,946	1,1
17042	hopa	15,075	-1,262	2,6
17074	kastamonu	17,515	-1,579	1,8
17080	çankırı	6,93	-1,895	0,6
17083	merzifon-amasya	14,929	-1,579	1,2
17090	sivas	16,502	-1,895	0,4
17097	kars	9,135	-2,212	2,4
17100	ığdır	14,057	-2,212	1,9
17110	gökçeada	8,268	-0,313	1,1
17114	bandırma	19,882	-0,946	0
17130	ankara	14,282	-0,946	1,4
17160	kırşehir	12,562	-0,946	0,8
17192	aksaray	12,966	-1,579	0,5
17193	nevşehir	14,472	-1,262	0,1
17199	malatya	6,634	-0,946	2,1
17201	elazığ	11,634	-0,313	0,6
17220	izmir	10,4	-1,579	0,2
17238	burdur	14,865	-0,946	0,1
17246	karaman	12,297	-0,629	1,6
17250	niğde	11,922	-1,579	0
17265	adıyaman	18,614	-0,313	1
17275	mardin	7,096	-1,895	1,9
17285	hakkari	9,725	-1,579	2,3
17370	iskenderun	13,468	0,637	0,3
17375	finike	18,006	-1,579	0,2
17610	şile	9,333	-1,262	3,1
17624	ünye	20,346	-0,946	2,8
17632	ipsala edirne	8,094	0,004	3,5
17768	çemişgezek	12,547	-0,313	5,7
17776	solhan bingöl	12,003	-1,579	2,5
17804	keban elazığ	6,012	-0,946	0,7
17866	göksun maraş	13,552	-1,579	1,7
17912	siverek	13,407	-0,946	2,7
17966	birecik urfa	19,045	-0,313	0,6

2.4 Trend Analysis

After the homogeneity consideration the last statistical step is trend analysis. The Mann-Kendall trend test is widely used in analysis of climatic data. It is also known as Kendall's τ statistic. The basic algorithm of the Mann-Kendall test is summarized from Partal and Kahya [27]. This test is a rank based test similar to the Kruskal-Wallis test. Rank based tests have some advantages. They are robust to data sets which have extreme values and exhibits good performance for the data sets with skewed variables.

For the Mann-Kendall trend test, the null hypothesis (h_0) is given as: the data set (x_1, $x_{2…}$ x_n) is randomly distributed through the years. In other words, there is no trend in the data set.

Alternative hypothesis (h_1) can be stated as: there is a trend in the data set.

The test statistics (S) is given by

$$S = \sum_{k=1}^{n} \sum_{j=k+1}^{n} sgn(x_j - x_k) \quad (2.5)$$

$$sgn(x_j - x_k) = 1 \quad \text{if} \quad (x_j - x_k) > 0 \quad (2.6)$$

$$sgn(x_j - x_k) = -1 \quad \text{if} \quad (x_j - x_k) < 0 \quad (2.7)$$

$$sgn(x_j - x_k) = -1 \quad \text{if} \quad (x_j - x_k) = 0 \quad (2.8)$$

$$var(s) = \frac{[n(n-1)(2n+5) - \sum_t t(t-1)(2t+5)]}{18} \quad (2.9)$$

$$z = \frac{S-1}{\sqrt{var(S)}} \quad \text{if} \quad S > 0 \quad (2.10)$$

$$z = \frac{S+1}{\sqrt{var(S)}} \quad \text{if} \quad S < 0 \quad (2.11)$$

$$z = 0 \quad \text{if} \quad S = 0 \quad (2.12)$$

h_0 should be rejected if $|z| \geq 1.96$ where 1.96 is the critical value of z which comes from $\alpha = 0{,}05$ level of significance. If h_0 is rejected, positive S means increasing trend and negative S means decreasing trend. In this analysis, by excluding the less reliable data points, Sen's estimator (note that S is not the Sen's slope) algorithm calculates a slope of the trend line which is called Sen's slope. To assure further the trend of the data set, level of significance for the data set should also be taken into account. To do this, algorithm calculates a probability value for the data set which is called p value, and this value should be compared with the chosen level of significance (0,05). An example of a station that was determined as "no trend" although it has high Sen's slope due to its high p value is given in Appendix A.

As mentioned in introduction chapter, there are strong evidences about the *global dimming and brightening*. The period end of the 1950s and end of 1980s is *dimming* period and for recent years it is *brightening* period [2]. Also there are strong evidences for these trends in Turkey. Aksoy [8] and [17], showed the dimming and brightening periods in Turkey. These studies are summarized in introduction chapter. Due to the above mentioned reasons graph of each station's data set and a superposed version of all graphs were investigated. After the investigation, it is observed that there is a change in trend around the year 1990 for most of the station. So the data set is divided into two parts to examine if there is any trend. The division year determined approximately for each station. After determining the division year, Mann-Kendall trend analysis has been applied between the years 1970 to 2010, 1970 to around 1990 and around 1990 to 2010 by using XLSTAT which is a package program for Microsoft Excel. Analysis has been applied for annual, winter, spring, summer and autumn averages. Results of the trend analysis are given in the following chapter. Graphs of the yearly averages of each station are given in appendix B and also, in a single plot, variation of all the stations is presented in appendix C.

CHAPTER 3

RESULTS AND DISCUSSION

In this chapter, results of the trend analysis of SD data will be given and they will be interpreted. After this interpretation these results will be compared with other studies which are made by SD and satellite derived data. And SD trends are also compared with temperature trend analysis of some studies.

3.1 Results of the Trend Analysis

Due to the *global dimming and brightening*, the data sets of each station have been investigated one by one and it is clarified if there is a change in the trend around 1990s. So the trend analysis has been done between 1970 and 2010; and separately between 1970 and 1990 and between 1990 and 2010. For each period, trend analysis has been carried out for the annual averages, and for the winter, spring, summer and autumn averages. Results of these analyses are given in Table 3.1 and 3.2. We also included the p values of all the locations in Table 3.3 so that the most reliable Sen's slope results (Table 3.2; values that are framed and bold) be traced by comparing p values with the chosen level of significance (0,05). The results of the trend analysis can be seen in Figure 3.1 to 3.3 also.

Firstly, trend of sites between 1970 and 2010 (overall trend) has been interpreted.

For yearly averages: most of the sites (22 sites) have no significant trend. This result was expected because all the data between 1970 and 2010 was investigated, so that dimming and brightening periods cannot be differentiated. However, there is a remarkable negative trend at south-east part of Turkey. Trends of 7 sites (Adıyaman, Hakkari, Solhan, Göksun, Birecik and Siverek) are negative between 1970 and 2010. And two sites which are at the central part the country (Karaman and Burdur) have also negative trends. Five other stations which have significant results either negative or positive are not from a certain region but rather evenly distributed. In addition, it should be noted that most of the significant trend results are negative. Only two sites (Hopa and Şile-İstanbul) have significant positive trend.

For winter averages: there are no significant trends for the analyzed sites except Ordu. Ordu has significant trend value and it is negative. For spring averages: only 3 sites have significant trend and they are positive trends. And these sites are not in a certain region. They are arbitrarily located. For summer averages: again most of the sites have no significant trend value however there is negative trend at south-east part of Turkey. 7 of the sites (Adıyaman, Malatya, Göksun, Solhan, Birecik, Siverek and Hakkari) have negative trend values. Only one of the 36 sites has positive trend. For autumn averages: about the half of the sites (19 station) has negative trend values. Two of them are at north-west part of Turkey (Gökçeada and Bandırma); five of them at the center of the country (Ankara, Nevşehir, Aksaray, Burdur and Karaman) and 6 of them are at the south-east part of Turkey (Adıyaman, Malatya, Göksun, Solhan, Birecik, İskenderun).

Secondly, trend of SD values between 1970 and around 1990s of the sites have been investigated. Followings are the discussion of the results.
For yearly averages: 27 of the sites have negative trend and other 9 sites have no trend. This is expected result in accord with a lot of researches all over the world. The sites which have no trend are not localized at a certain region. Average of the Sen's slope (slope of the trend lines calculated by Sen's slope estimator algorithm) of 27 sites is *-0.043* and that means that average decrease of SD of

these sites is 4.3%. Average Sen's slope of all sites is *-0.035*, which means a *3.5%* decrease of SD values. However, we should note that the letter values are less reliable as it is the average of all without considering the level of significance check.
For winter averages, 21 of the sites have no significant trend and 15 of them have significant negative trends. These 15 sites are not localized at a certain region. For spring averages, only 7 of the sites have significant negative trend and 29 of the sites have no trends. These 7 sites are not localized in a certain region again. For summer averages, 12 of the sites have significant negative trends and remaining 24 sites has no significant trend. 7 of these 12 sites are localized at south-east part of Turkey (Malatya, Elazığ, Adıyaman, Birecik, Siverek, Göksun and Keban). For autumn averages, 14 of the sites have significant negative trend and remaining sites have no trend. 2 of the sites which have negative trends are at the east part of Turkey (Kars and Iğdır), 4 of them are at the central part of Turkey (Sivas, Aksaray, Nevsehir and Nigde) and 6 of them at the south part of Turkey (Birecik, Siverek, Göksun, Keban, Solhan and İskenderun). Negative trends are mostly during winter and autumn which might be attributed to increase in the air pollution [8].

Thirdly, trend of SD values between, around 1990 and 2010 has been investigated. A clear overall brightening could not be observed. Followings are the result of investigations for this period.

For yearly averages: 4 of the sites have positive trends and these are at the north part of Turkey (Sile, Unye, Ordu and Hopa). 4 of the sites have significant negative trends and 3 of them the south-east part (Adıyaman, Siverek and Hakkari) and one of them is at the south part of Turkey (Finike). Other sites have no significant trends. For these regions we might conclude that, although negative trend is observed, the rate of decrease is considerably smaller (see table 3.2).

For winter averages: 34 of the sites have no significant trends and only 2 sites have significant trend. The station which has negative trend is at the south (Finike) and which has positive trend is at the north (Hopa). For spring averages: 4 of the sites have significant positive trend and three of them at the north part of Turkey (İnebolu, Ordu and Ünye). Two of the sites have negative trend and these are not localized at any part and 30 of the sites has no significant trend. For summer averages: 3 of the sites have positive trends and two of them are again at the north part (Ordu and Hopa). 5 of the sites have significant negative trend and 3 of them are at the south-east part of the Turkey (Adıyaman, Hakkari and Siverek). For autumn averages: 5 of the sites have significant negative trend and others have no trend. 3 of these 5 sites are at the north-west part of the Turkey (Gökçeada, Bandırma and İpsala). 31 of the stations have no trend. Thus, seasonal investigations support that the negative trends are either stopped or their rate decreased. This might be treated as being in accord with global brightening but it should be noted that a clear positive trend for a considerable number of sites could not be observed.

3.2 Discussions

Aksoy [8] studied with SD values of Turkey for 34 stations between the years 1960 and 1994 and he calculated SSR by using a modified version of Ögelman's equation [28] which is summarized in introduction chapter. In this study Aksoy used linear regression equations to analyze the trends of the data sets and found a dimming trend with *-3.4%* in the mentioned period. Most of the sites of Aksoy's study were different than in the present research and also the time period does not overlap completely. However the concurrence in dimming is remarkable. However, there is also a slightly different result. In Aksoy's study, although Mardin has a positive trend, in this thesis none of the sites has positive trend at the south-east part of the Turkey.

Aksoy [17] studied with Satellite-based radiation data at the surface of the Earth taken from National Aeronautics and Space Administration (NASA). This study has been summarized in introduction chapter. He studied with 85 grid cells between July 1983 and December 2005. By using the Mann–Kendall rank correlation test he analyzed the trends of each grid cell and found significant increasing trend; that is 73% of the grid cells have positive trends and 27% of have no trend. Most of the increasing trends begin in the period 1995–1997 and for a considerable number of sites brightening begins in 1991. It is obvious that there is no clear agreement between the results of Aksoy [17] and this thesis for the period of brightening.

The main reason of variations of SD and SSR are the variations in atmospheric aerosols. Aerosols can affect SD and SSR measurements directly or indirectly by modifying cloud formation [2]. It should be noted that increase in the aerosol of the atmosphere can result in decrease of SD measurements, especially for the instants when the SSR values are close to the threshold value of the instrument. Recently, spatial and temporal variation of aerosol optical thickness (AOT) in the eastern Mediterranean basin were studied by Hatzianastassiou et al. [29]. Their results showed that AOT variations can be attributed to dust coming from the North Africa (especially from Sahara Desert). Due to this reason they concluded that AOT decreases towards the north. In this thesis of SD trend analysis, the results showed that after 1990s the north part of Turkey has positive trend but the south part has negative trend. So the reasons for our result of an increasing trend at the North Coastal of Turkey can be explained by the results Hatzianastassiou et al. obtained for East Mediterranean basin.

Comparing air temperature with sunshine duration (SD) data can be meaningful. Study of Kadıoğlu [30] investigates the trends in surface air temperature data over Turkey for 17 stations between 1939 and 1989. He found a warming trend between 1939 and 1989 and cooling trend between 1955 and 1989. It can be seen in Table 3.4 that average trend values of maximum, minimum and mean temperature measurements are negative for 17 stations between 1955 and 1989. Especially for the north part of the Turkey, negative trend is much more remarkable. Cooling trend of this period is in concurrence with the trend of SD value in 1970 to around 1990. A statistical comparison is needed to compare temperature and SD measurements more accurately however that statistical comparison is beyond the scope of this study.

Also studies of Türkeş [31] and [32] and also Türkeş et al. [33] indicate negative trends between the late 1960s and early 1990s for air temperatures. One of the main results of Türkeş's investigations is that the minimum annual air temperature has an increasing trend after 1980s. This is in accord with Aksoy's results of satellite derived data and partly agrees the results of this thesis.

Table 3.1 Trends of each station for annual, winter, spring, summer and autumn averages. '*0*' represents no significant trend, '*+*' represents significant positive trend and '*-*' represents significant negative trend with $\alpha = 0.005$ level of significance. At Columns; '*1*' denotes the period between 1970 and around 1990, '*2*' denotes the period between around 1990 and 2010 and if the column has no number it denotes the period between 1970 and 2010.

station code	name of station	division year	winter2	spring2	summer2	autumn2	annual2	winter1	spring1	summer1	autumn1	annual1	winter	spring	summer	autumn	annual
17024	inebolu	1989	0	+	0	0	0	0	0	-	0	-	0	0	0	0	0
17033	ordu	1988	0	+	+	0	+	-	0	0	0	-	-	0	0	-	0
17040	rize	1992	0	0	0	0	0	-	0	0	0	-	0	0	0	0	0
17042	hopa	1987	+	0	+	0	+	0	0	0	0	0	0	0	+	0	+
17074	kastamonu	1991	0	0	0	0	0	0	0	0	-	-	0	0	0	-	-
17080	çankırı	1992	0	0	+	0	0	0	0	0	0	0	0	0	0	0	0
17083	merzifon-amasya	1991	0	+	0	0	0	0	0	0	0	-	0	0	0	-	-
17090	sivas	1989	0	0	0	0	0	-	-	-	-	-	0	0	0	0	0
17097	kars	1989	0	0	0	0	0	-	0	0	-	-	0	0	0	0	0
17100	ığdır	1989	0	-	0	0	0	-	-	-	-	-	0	0	0	0	0
17110	gökçeada	1989	0	0	0	-	0	0	0	0	0	0	0	0	0	-	0
17114	bandırma	1992	0	0	0	-	0	0	0	-	0	-	0	0	-	-	-
17130	ankara	1992	0	0	0	-	0	0	0	-	0	0	0	0	-	-	0
17160	kırşehir	1992	0	0	0	0	0	0	0	0	0	0	0	+	0	0	0
17192	aksaray	1992	0	0	0	0	0	-	0	0	-	-	0	0	0	-	0
17193	nevşehir	1989	0	0	0	0	0	-	0	0	-	-	0	0	0	-	0
17199	malatya	1989	0	0	0	0	0	0	0	-	-	-	0	0	-	0	0
17201	elazığ	1989	0	0	0	0	0	0	0	-	0	0	0	0	0	+	0
17220	izmir	1989	0	0	-	0	0	-	0	0	0	-	0	0	0	-	0
17238	burdur	1989	0	0	0	0	0	-	-	0	0	-	0	0	-	-	-
17246	karaman	1989	0	0	0	0	0	0	0	0	0	-	0	0	0	-	-
17250	niğde	1989	0	0	0	0	0	0	0	0	-	-	0	0	0	0	0
17265	adıyaman	1989	0	0	-	-	-	0	0	-	0	-	0	0	-	-	-
17275	mardin	1989	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17285	hakkari	1989	0	0	-	0	-	0	0	0	0	-	0	0	-	0	-
17370	iskenderun	1989	0	0	0	0	0	-	-	0	-	-	0	0	0	-	0
17375	finike	1989	-	0	-	0	-	-	-	0	0	-	0	0	-	-	-
17610	şile	1991	0	0	0	0	+	0	0	0	0	0	0	+	0	0	+
17624	ünye	1988	0	+	0	0	+	-	-	0	0	-	0	0	0	0	0
17632	ipsala edirne	1991	0	0	0	-	0	0	0	0	0	0	0	0	0	-	0
17768	çemişgezek	1989	0	0	0	0	0	0	0	0	0	-	0	+	0	0	0
17776	solhan bingöl	1989	0	0	0	0	0	-	0	0	-	-	0	0	-	-	-
17804	keban elazığ	1989	0	0	0	0	0	0	0	-	-	-	0	0	0	0	0
17866	göksun maraş	1989	0	0	0	0	0	0	0	-	-	-	0	0	-	-	-
17912	siverek	1989	0	-	-	0	-	-	0	-	-	-	0	0	-	-	-
17966	birecik urfa	1989	0	0	0	0	0	-	-	-	-	-	0	0	-	-	-

Table 3.2. Sen's slope of trends of each station. Framed and bold cells passed the trend test.

station code	name of station	devision year	winter2	spring2	summer2	autumn2	annual2	winter1	spring1	summer1	autumn1	annual1	winter	spring	summer	autumn	annual
17024	inebolu	1989	-0,021	**0,049**	0,026	-0,002	0,012	-0,037	-0,037	**-0,062**	-0,022	**-0,049**	-0,002	0,021	-0,002	-0,007	0,000
17033	ordu	1988	0,011	**0,034**	**0,058**	0,000	**0,026**	**-0,047**	-0,032	-0,050	-0,020	**-0,043**	**-0,020**	0,004	0,001	**-0,015**	-0,008
17040	rize	1992	0,023	-0,001	0,033	0,007	0,018	**-0,050**	-0,017	-0,015	-0,025	**-0,030**	-0,008	-0,002	0,009	0,000	0,000
17042	hopa	1987	**0,027**	0,017	**0,068**	0,002	**0,033**	-0,028	-0,027	0,013	-0,009	-0,013	-0,004	0,013	**0,022**	0,008	**0,010**
17074	kastamonu	1991	-0,025	0,013	-0,013	-0,035	-0,015	-0,016	-0,035	-0,030	**-0,049**	**-0,036**	-0,011	-0,009	-0,024	**-0,028**	**-0,018**
17080	çankırı	1992	-0,035	0,034	**0,066**	-0,023	0,006	0,008	-0,015	-0,032	-0,028	-0,012	0,004	0,016	0,002	-0,003	0,005
17083	merzifon-amasya	1991	-0,005	**0,050**	0,051	0,004	0,021	-0,013	-0,025	-0,055	-0,035	**-0,035**	-0,012	-0,002	-0,009	**-0,017**	**-0,010**
17090	sivas	1989	0,015	0,020	-0,009	0,002	0,005	**-0,061**	**-0,056**	**-0,058**	**-0,079**	**-0,059**	0,002	0,015	0,005	-0,006	0,004
17097	kars	1989	0,017	**-0,016**	0,018	0,030	0,003	**-0,073**	-0,018	-0,030	**-0,060**	**-0,040**	0,012	0,006	-0,008	-0,008	-0,001
17100	ığdır	1989	-0,037	**-0,043**	0,005	0,018	-0,014	**-0,059**	**-0,048**	**-0,050**	**-0,081**	**-0,070**	-0,001	0,001	-0,006	0,003	-0,002
17110	gökçeada	1989	-0,030	0,026	0,033	**-0,024**	0,000	-0,014	-0,017	-0,022	-0,007	-0,018	0,005	0,014	0,007	**-0,012**	0,003
17114	bandırma	1992	-0,031	0,009	-0,037	**-0,042**	-0,015	-0,032	-0,031	**-0,055**	-0,041	**-0,037**	-0,013	0,004	**-0,020**	**-0,027**	**-0,013**
17130	ankara	1992	-0,039	-0,021	-0,047	**-0,047**	-0,031	-0,009	-0,023	**-0,059**	-0,030	-0,027	-0,003	-0,004	**-0,027**	**-0,019**	-0,010
17160	kırşehir	1992	0,054	0,024	0,025	0,002	0,021	-0,020	-0,003	0,011	-0,017	-0,002	0,007	**0,017**	0,001	0,006	0,008
17192	aksaray	1992	0,001	0,002	-0,004	-0,040	-0,004	**-0,059**	-0,028	-0,011	**-0,051**	**-0,035**	0,001	0,005	-0,011	**-0,021**	-0,006
17193	nevşehir	1989	0,004	-0,001	-0,003	-0,004	0,001	**-0,069**	-0,030	-0,027	**-0,069**	**-0,050**	-0,011	0,010	0,006	**-0,012**	-0,002
17199	malatya	1989	-0,019	-0,009	-0,020	0,034	-0,002	-0,057	-0,019	**-0,044**	**-0,069**	**-0,047**	0,012	0,009	**-0,025**	0,006	0,002
17201	elazığ	1989	-0,015	-0,009	-0,025	0,014	-0,007	0,003	-0,034	**-0,035**	-0,026	-0,021	0,016	0,009	-0,007	**0,014**	0,009
17220	izmir	1989	-0,019	-0,008	**-0,024**	-0,005	-0,011	**-0,095**	-0,033	-0,018	-0,035	**-0,044**	-0,005	0,003	-0,005	**-0,015**	-0,007
17238	burdur	1989	-0,020	0,007	-0,008	-0,002	-0,004	**-0,073**	**-0,061**	-0,022	-0,029	**-0,043**	-0,004	-0,002	**-0,017**	**-0,012**	**-0,008**
17246	karaman	1989	0,018	0,022	0,005	-0,001	0,008	-0,026	-0,030	-0,014	-0,047	**-0,026**	-0,013	0,004	-0,005	**-0,019**	**-0,008**
17250	niğde	1989	0,009	-0,003	0,009	-0,007	0,004	-0,040	-0,018	-0,020	**-0,057**	**-0,035**	0,006	0,005	-0,002	-0,006	0,002
17265	adıyaman	1989	-0,078	-0,057	**-0,042**	**-0,035**	**-0,037**	-0,048	-0,027	**-0,026**	-0,030	**-0,031**	-0,018	-0,013	**-0,036**	**-0,028**	**-0,023**
17275	mardin	1989	-0,017	-0,008	-0,013	-0,001	-0,009	-0,065	-0,011	-0,007	-0,029	-0,016	-0,002	0,012	0,001	-0,003	0,004
17285	hakkari	1989	-0,013	-0,060	**-0,043**	-0,013	**-0,026**	-0,056	0,003	-0,031	**-0,042**	**-0,033**	-0,006	-0,004	**-0,017**	-0,008	**-0,009**
17370	iskenderun	1989	-0,024	-0,009	0,006	0,006	-0,008	**-0,076**	**-0,054**	0,008	**-0,045**	**-0,044**	-0,004	-0,001	-0,011	**-0,015**	-0,008
17375	finike	1989	**-0,063**	0,007	**-0,014**	-0,015	**-0,018**	**-0,038**	**-0,068**	-0,029	-0,029	**-0,036**	-0,009	-0,003	**-0,025**	**-0,016**	**-0,014**
17610	şile	1991	0,021	0,064	0,071	-0,007	**0,041**	0,004	0,020	0,018	0,000	0,010	0,006	**0,022**	0,016	-0,004	**0,010**
17624	ünye	1988	0,017	**0,050**	0,036	0,023	**0,038**	**-0,060**	**-0,071**	-0,067	-0,032	**-0,056**	-0,010	0,014	0,004	0,000	0,002
17632	ipsala edirne	1991	-0,040	0,008	-0,001	**-0,041**	-0,015	-0,010	0,010	-0,022	-0,004	-0,003	0,006	0,011	0,005	**-0,016**	0,001
17768	çemişgezek	1989	-0,020	-0,020	-0,012	-0,019	-0,013	-0,027	0,002	-0,012	-0,041	**-0,022**	0,010	**0,025**	0,005	-0,005	0,007
17776	solhan bingöl	1989	-0,017	-0,050	-0,002	-0,009	-0,016	**-0,106**	-0,044	-0,012	**-0,067**	**-0,053**	-0,007	-0,007	**-0,017**	**-0,013**	**-0,012**
17804	keban elazığ	1989	-0,036	-0,020	-0,008	0,021	-0,006	-0,039	-0,036	**-0,017**	**-0,042**	**-0,040**	0,009	0,013	-0,005	-0,003	0,003
17866	göksun maraş	1989	-0,028	0,023	0,022	0,001	0,010	-0,036	-0,034	**-0,077**	**-0,046**	**-0,048**	-0,007	0,007	**-0,019**	**-0,023**	**-0,011**
17912	siverek	1989	-0,037	**-0,048**	**-0,036**	-0,010	**-0,032**	**-0,067**	-0,011	**-0,040**	**-0,055**	**-0,053**	-0,016	-0,006	**-0,020**	**-0,022**	**-0,016**
17966	birecik urfa	1989	-0,004	-0,011	-0,010	0,008	0,002	**-0,088**	**-0,068**	**-0,087**	**-0,077**	**-0,076**	-0,005	-0,015	**-0,055**	**-0,018**	**-0,024**

Table 3.3. *p* values of the Mann-Kendall trend test. If the *p* value is bigger than 0.05, it means that there is no trend.

station code	name of station	devision year	winter2	spring2	summer2	autumn2	annual2	winter1	spring1	summer1	autumn1	annual1	winter	spring	summer	autumn	annual
17024	inebolu	1989	0,343	0,027	0,343	0,956	0,343	0,164	0,068	0,034	0,368	< 0,0001	0,763	0,067	0,885	0,309	0,920
17033	ordu	1988	0,715	0,026	0,007	1,000	0,012	0,017	0,260	0,229	0,229	0,007	0,004	0,510	0,956	0,035	0,148
17040	rize	1992	0,406	1,000	0,267	0,783	0,368	0,000	0,372	0,469	0,081	0,001	0,198	0,798	0,331	0,938	0,938
17042	hopa	1987	0,050	0,314	0,013	0,903	0,001	0,440	0,440	0,655	0,715	0,440	0,569	0,142	0,044	0,354	0,046
17074	kastamonu	1991	0,319	0,725	0,873	0,146	0,461	0,572	0,198	0,220	0,043	0,019	0,168	0,259	0,094	0,000	0,001
17080	çankırı	1992	0,068	0,164	0,041	0,211	0,629	0,781	0,469	0,161	0,198	0,315	0,696	0,067	0,798	0,647	0,268
17083	merzifon-amasya	1991	0,924	0,020	0,064	0,725	0,064	0,493	0,387	0,126	0,098	0,009	0,099	0,885	0,428	0,033	0,021
17090	sivas	1989	0,656	0,435	0,656	1,000	0,578	0,000	0,008	0,029	0,007	< 0,0001	0,713	0,086	0,525	0,428	0,342
17097	kars	1989	0,656	0,578	0,435	0,081	0,824	0,034	0,629	0,238	0,001	0,004	0,298	0,510	0,415	0,268	0,780
17100	ığdır	1989	0,289	0,027	0,868	0,198	0,264	0,019	0,034	0,013	0,000	< 0,0001	0,885	0,920	0,354	0,867	0,763
17110	gökçeada	1989	0,179	0,343	0,130	0,055	1,000	0,368	0,581	0,368	0,534	0,143	0,468	0,086	0,402	0,028	0,354
17114	bandırma	1992	0,489	0,783	0,108	0,041	0,238	0,179	0,198	0,031	0,081	0,008	0,104	0,763	0,026	0,001	0,003
17130	ankara	1992	0,211	0,730	0,093	0,041	0,143	0,739	0,315	0,004	0,116	0,063	0,680	0,746	0,010	0,007	0,060
17160	kırşehir	1992	0,143	0,406	0,298	0,945	0,108	0,343	0,868	0,504	0,403	0,868	0,354	0,018	0,867	0,454	0,057
17192	aksaray	1992	0,945	0,945	0,836	0,080	0,783	0,003	0,343	0,403	0,031	0,004	0,920	0,525	0,099	0,010	0,206
17193	nevşehir	1989	0,956	1,000	0,824	0,697	0,956	0,003	0,068	0,447	0,008	< 0,0001	0,130	0,099	0,600	0,054	0,713
17199	malatya	1989	0,617	0,578	0,116	0,071	0,739	0,093	0,298	0,007	0,002	0,016	0,168	0,354	< 0,0001	0,354	0,815
17201	elazığ	1989	0,532	0,699	0,126	0,493	0,655	0,873	0,351	0,014	0,209	0,186	0,090	0,390	0,231	0,042	0,130
17220	izmir	1989	0,540	0,617	0,092	0,697	0,403	0,001	0,298	0,164	0,125	0,001	0,713	0,713	0,309	0,004	0,190
17238	burdur	1989	0,315	0,656	0,343	0,781	0,578	0,002	0,058	0,211	0,164	0,000	0,616	0,832	0,005	0,015	0,016
17246	karaman	1989	0,372	0,372	0,656	0,956	0,435	0,447	0,143	0,447	0,186	0,049	0,125	0,428	0,320	0,023	0,044
17250	niğde	1989	0,697	0,824	0,739	0,656	0,578	0,125	0,093	0,368	0,029	0,007	0,510	0,510	0,798	0,365	0,569
17265	adıyaman	1989	0,081	0,063	0,008	0,007	0,007	0,238	0,447	0,049	0,211	0,010	0,168	0,206	< 0,0001	< 0,0001	< 0,0001
17275	mardin	1989	0,578	0,739	0,578	0,912	0,656	0,108	0,534	0,890	0,368	0,332	0,867	0,190	0,832	0,729	0,468
17285	hakkari	1989	0,540	0,071	0,020	0,435	0,048	0,093	0,945	0,368	0,108	0,029	0,441	0,631	0,016	0,161	0,033
17370	iskenderun	1989	0,435	0,781	0,912	0,617	0,617	0,019	0,058	0,836	0,001	0,001	0,647	0,956	0,415	0,002	0,086
17375	finike	1989	0,010	0,372	0,008	0,219	0,023	0,010	0,034	0,080	0,125	0,001	0,231	0,696	< 0,0001	0,000	< 0,0001
17610	şile	1991	0,501	0,165	0,074	0,725	0,055	0,882	0,387	0,387	0,976	0,098	0,309	0,012	0,142	0,569	0,016
17624	ünye	1988	0,190	0,002	0,172	0,295	0,009	0,014	0,021	0,112	0,330	0,000	0,309	0,114	0,746	0,973	0,815
17632	ipsala edirne	1991	0,209	0,773	0,974	0,034	0,351	0,835	0,789	0,493	0,835	0,929	0,496	0,206	0,600	0,007	0,902
17768	çemişgezek	1989	0,343	0,372	0,198	0,198	0,289	0,211	0,945	0,332	0,108	0,041	0,377	0,010	0,130	0,288	0,064
17776	solhan bingöl	1989	0,435	0,063	0,781	0,469	0,403	0,007	0,238	0,489	0,001	< 0,0001	0,525	0,482	0,001	0,012	0,016
17804	keban elazığ	1989	0,241	0,219	0,504	0,264	0,697	0,211	0,211	0,024	0,041	0,016	0,415	0,148	0,155	0,584	0,539
17866	göksun maraş	1989	0,372	0,343	0,092	1,000	0,315	0,447	0,143	0,008	0,034	0,000	0,663	0,342	0,037	0,002	0,028
17912	siverek	1989	0,343	0,055	0,048	0,315	0,014	0,041	0,489	0,016	0,001	0,004	0,231	0,496	0,000	< 0,0001	0,002
17966	birecik urfa	1989	0,912	0,739	0,315	0,697	1,000	0,041	0,016	< 0,0001	0,000	< 0,0001	0,696	0,094	< 0,0001	0,011	0,000

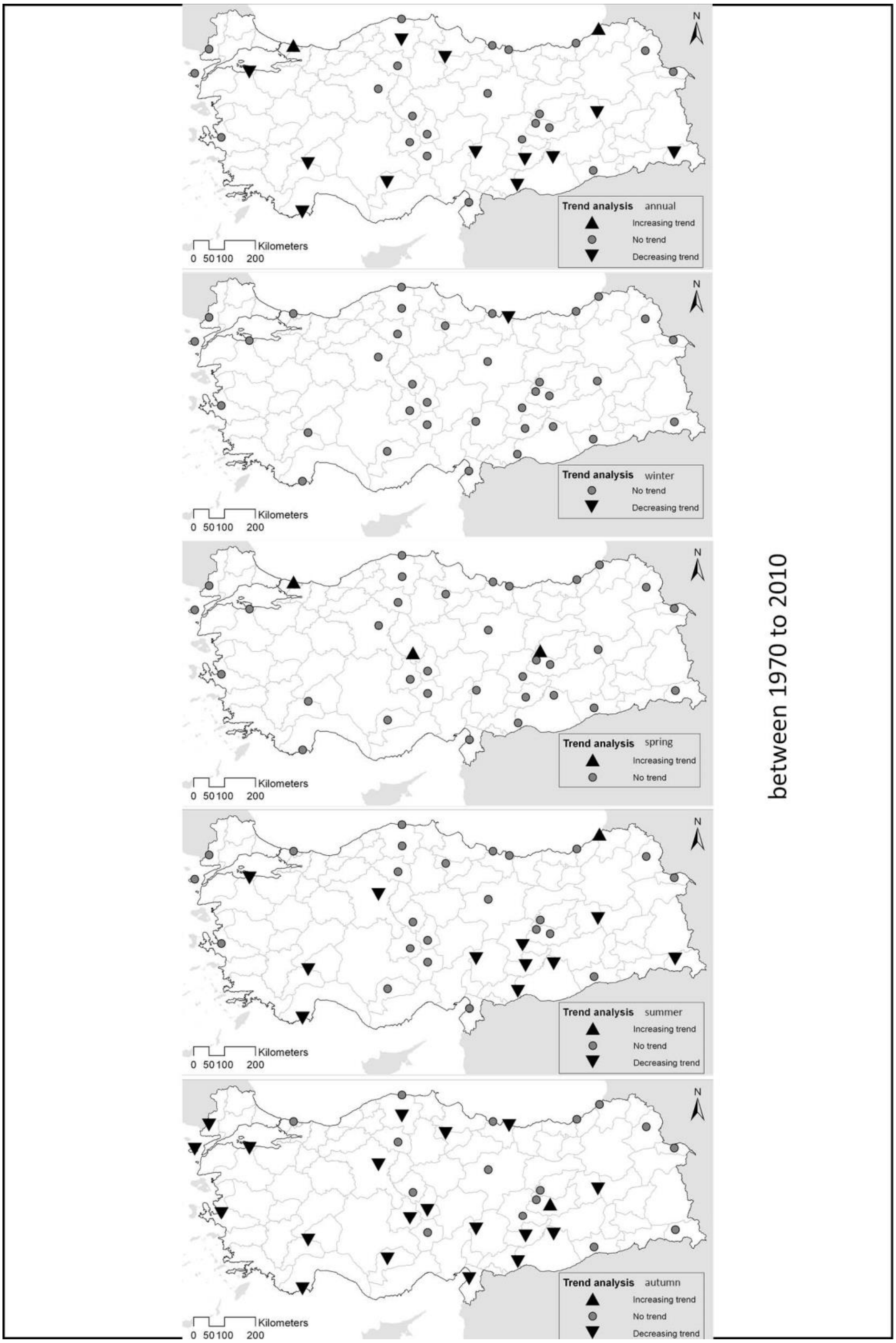

Figure 3.1. Results of trend analysis between 1970 and 2010 for annual, winter, spring, summer and autumn averages.

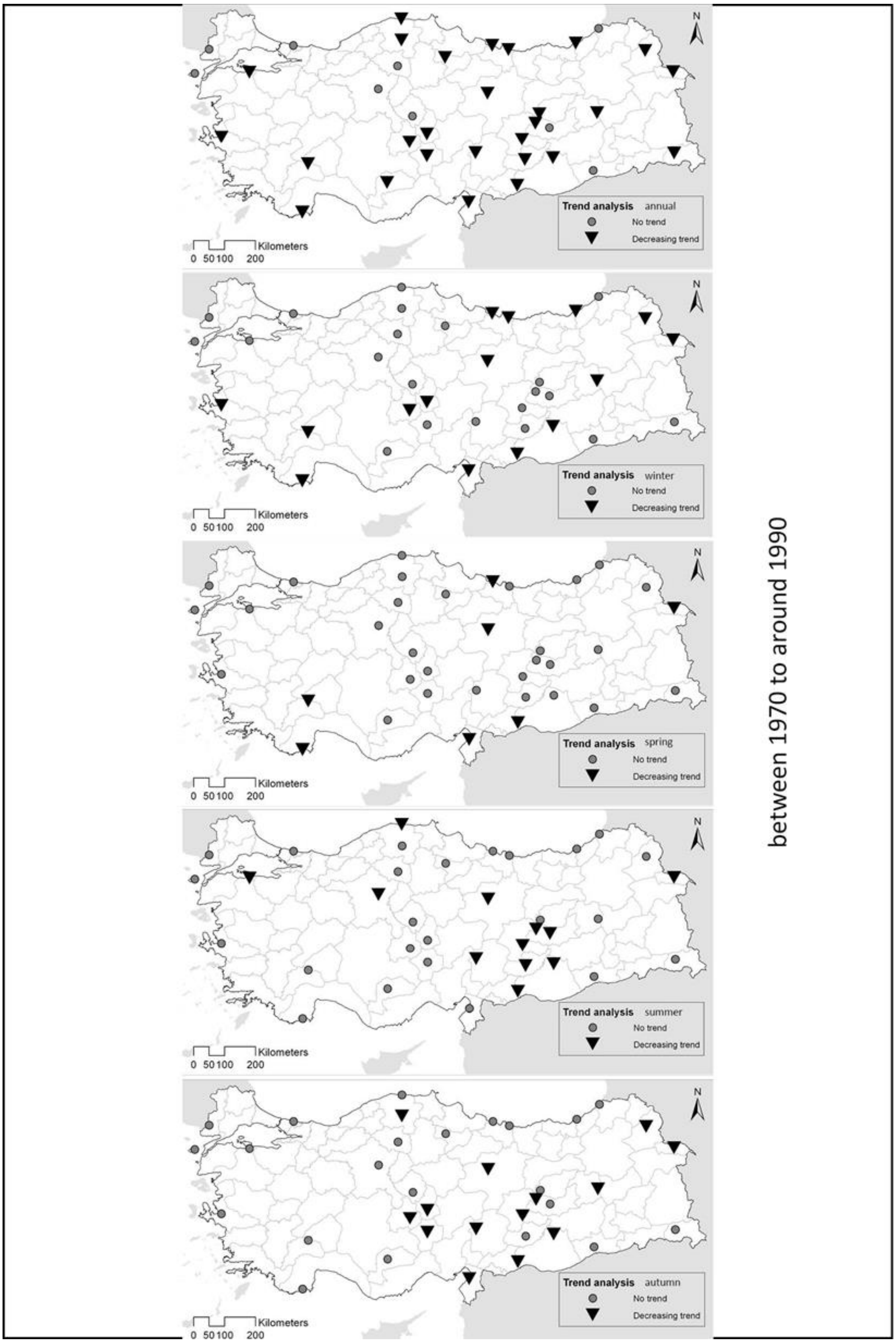

Figure 3.2. Results of trend analysis between 1970 and around 1990 for annual, winter, spring, summer and autumn averages.

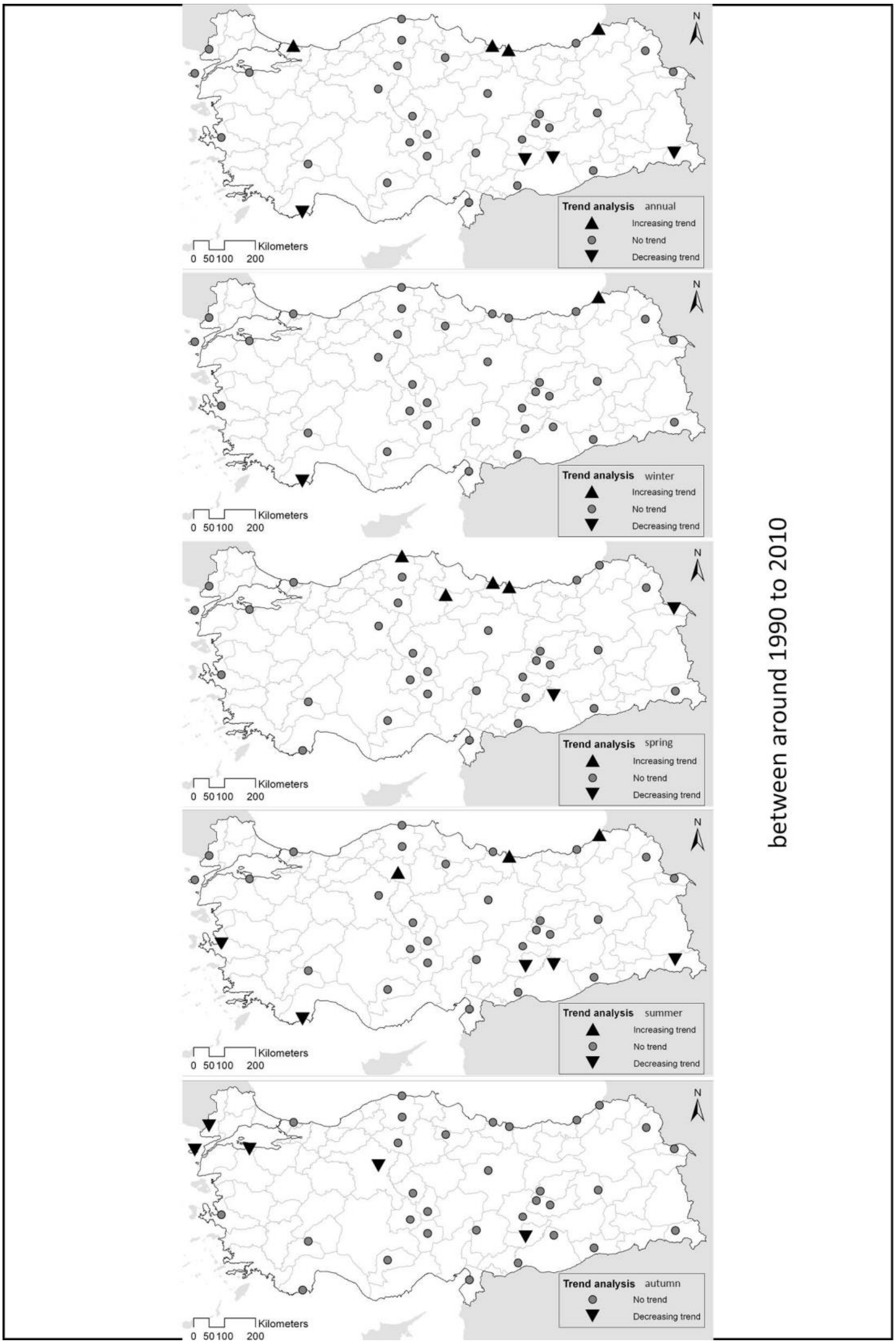

Figure 3.3. Results of trend analysis between around 1990 and 2010 for annual, winter, spring, summer and autumn averages.

Table 3.4. Annual trend values of maximum, minimum and mean temperature measurements between 1955 and 1989. Table is taken from Kadıoğlu [30].

Station	Minimum	Maximum	Mean
Edirne	−1·08	0·63	−0·31
Zonguldak	−1·62	−2·37*	−1·96*
Samsun	−2·53**	2·86**	−2·78**
Trabzon	−2·49**	−2·53**	− 2·41*
Göztepe	1·80	−1·55	0·14
Kars	2·14*	0·28	1·21
Çanakkale	1·23	−3·02**	−1·17
Ankara	−0·23	−0·38	−0·08
Sivas	1·24	−0·82	0·16
Kütahya	0·00	−0·04	0·06
Elaziğ	1·73	−0·14	0·78
Van	1·65	0·75	1·39
İzmir	−0·12	−0·61	−0·25
Konya	0·94	−0·74	−0·49
Diyarbakir	−0·78	−1·89*	−1·36
Ş. Urfa	1·73	−0·69	0·65
Adana	3·39**	−0·68	1·53
Average	−0·04	−1·33	−0·81

*Significant at the 5 per cent level. **Significant at the 1 per cent level.

CHAPTER 4

CONCLUSIONS

Data set of 192 stations of sunshine duration (SD) was obtained from Turkish State Meteorological Service (TSMS). Data set contains daily values of bright sunshine duration for the years 1970 to 2010. The data set is analyzed in terms of missing value, and observed that data set of 73 stations has missing values less than 6%. To reach more accurate results all other stations were eliminated at the beginning of the analysis.

Missing values of these 73 stations were imputed by using expectation maximization (EM) algorithm. After imputing missing values the data sets were investigated to determine which of them are homogenous and which are not. To determine homogeneity the nonparametric Kruskal-Wallis and Wald-Wolfowitz runs tests have been used. For homogeneity meta-data analysis were not considered due to lack of reliable meta-data files. As result of homogeneity considerations, data set of 36 of stations determined to be homogenous.

Trends of these 36 stations are analyzed by using The Mann-Kendall trend test. Due to the globally observed *global dimming and brightening* [2], it is also expected to reach similar results for SD data of Turkey. The graph of each station was investigated and it was observed that if there was a change of trend in the data set, it is around the 1990 in accord with global findings. So the trends of stations have been analyzed between 1970 and 2010, and also the whole data is divided into two yearly time intervals as: from 1970 to around 1990s and, from around 1990s to 2010.

There is a remarkable decreasing trend of SD value between 1970 and around 1990 especially in yearly averages. And in general, the negative trend after around 1990 does not continue moreover it turns to positive trend in north-costal part (4 sites of the north part has positive trend). Although 9 sites have negative trend between 1970 and 2010 (7 of them are at the south-east part and 2 of them are central part) 4 of these sites have negative trend (3 of them at the south-east part) after around 1990. It is observed that negative trend slows down after around 1990 which seemed partly in agreement with global results. Nevertheless, there is still a negative trend for three of the locations of south-east part of Turkey out of 9 stations. For the others, there are no significant negative or positive trends.

The results of the period 1970 and around 1990 are clearly in agreement with the global fact known as *global dimming and brightening* and agrees also with the results of Aksoy's study [8]. However the results of the period between around 1990 and 2010 are not in concurrence with global brightening, although results of the satellite derived SSR of study of Aksoy is in agreement. [17]. For the dimming period, there is a remarkable concurrency with the air temperature trends obtained by Türkeş (1995) and (1996a), and also with the results of Türkeş et al. (1995) and Kadıoğlu (1997), between the late 1960s and early 1990s [34] and the results of this thesis between 1970 and around 1990.

The important conclusion of the present research is the agreement of SD data to the global dimming and brightening periods for the years 1970 to 2010. However, as for most of such studies, present work could not clearly determine a human induced climate change. However, dimming between 1970 to 1990s might be attributed to air pollution at the locations where the measuring systems are installed[8].

The future research topics are to apply such tests to different climatological parameters that are measured for longer time periods. Cloudiness and humidity might be some of these parameters to be investigated. Estimations of SSR by the models which use more than one measured meteorological parameter (including the bright sunshine hours) may be helpful to combine the information hindered in these long term data sets.

May be the most important future prospect is the combination of accumulated satellite data (about 30 years) with surface measured climatic data to reach better analysis of recent trends. These researches certainly will give significant contributions to climate change issues, to clarify especially human induced climate change.

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APPENDIX A

AN EXAMPLE OF THE REJECTED TREND VALUE OF A STATION

Mann-Kendall trend test / Two-tailed test (3,29599555061179):

Kendall's tau	-0,273
S	-63,000
Var(S)	0,000
p-value (Two-tailed)	0,081
alpha	0,05

The p-value is computed using an exact method.

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is greater than the significance level alpha=0,05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 8,11%.

Sen's slope:	-0,078
Confidence interval:	] -0,638 ; 0,416 [

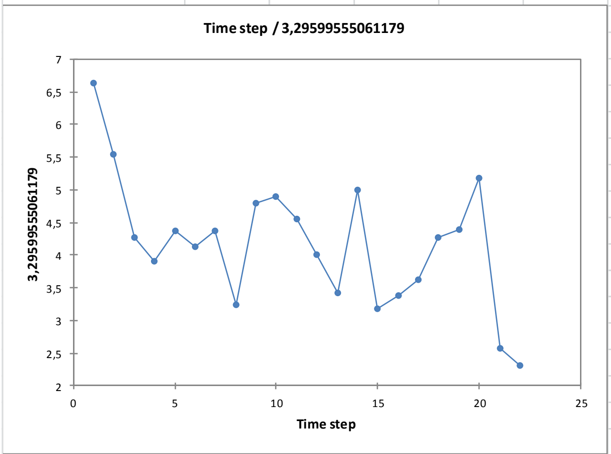


Figure A.1. An example of rejected trend value of a data set (Adıyaman; winter2) due to high *p* value although the Sen's slope gave very high value of decreasing trend.

APPENDIX B

GRAPHS OF THE ALL STATIONS

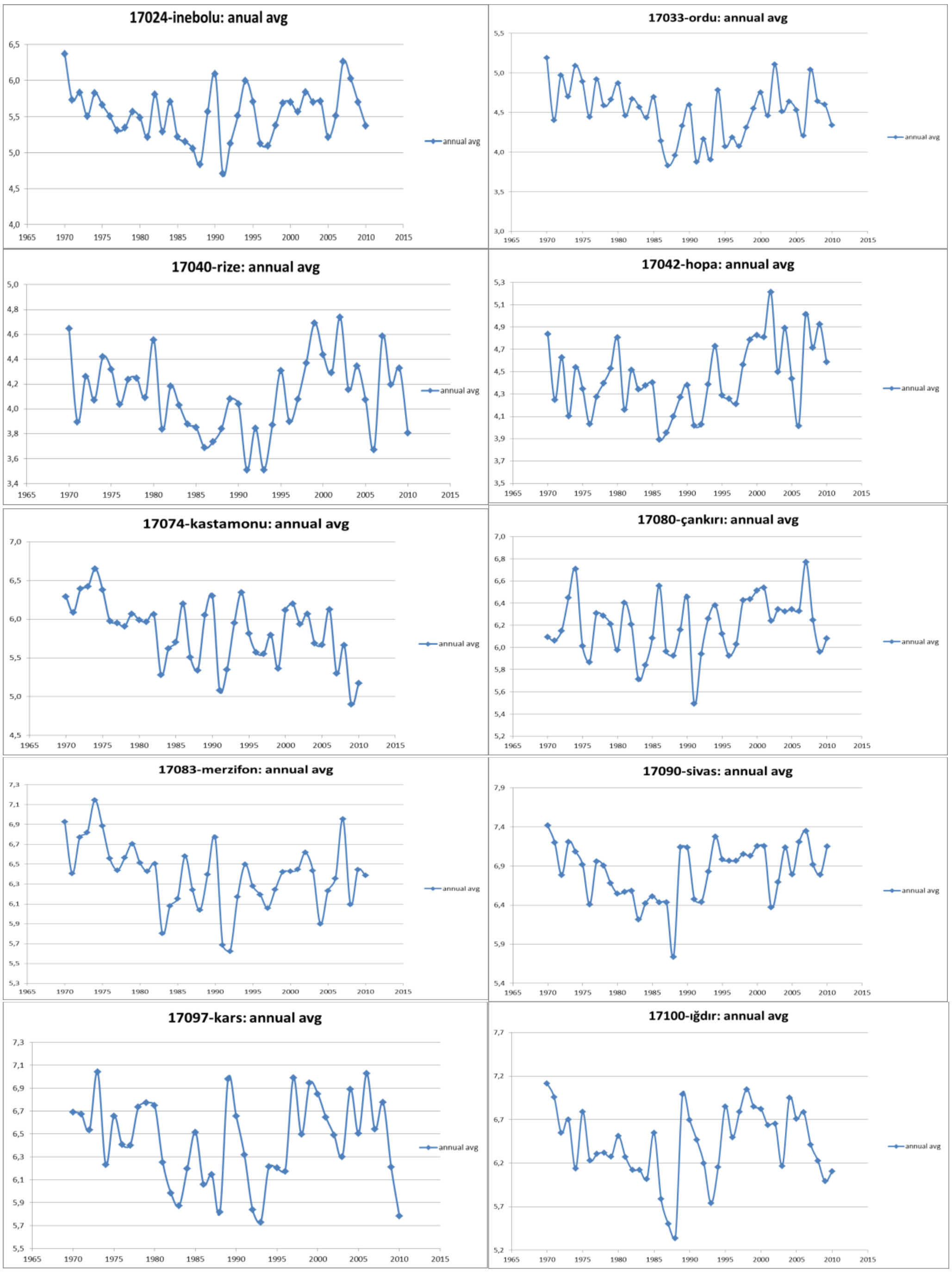


Figure B.1. Graph of each station which are determined as homogenous. Vertical axis represents SD in hours and horizontal axis represents the years.

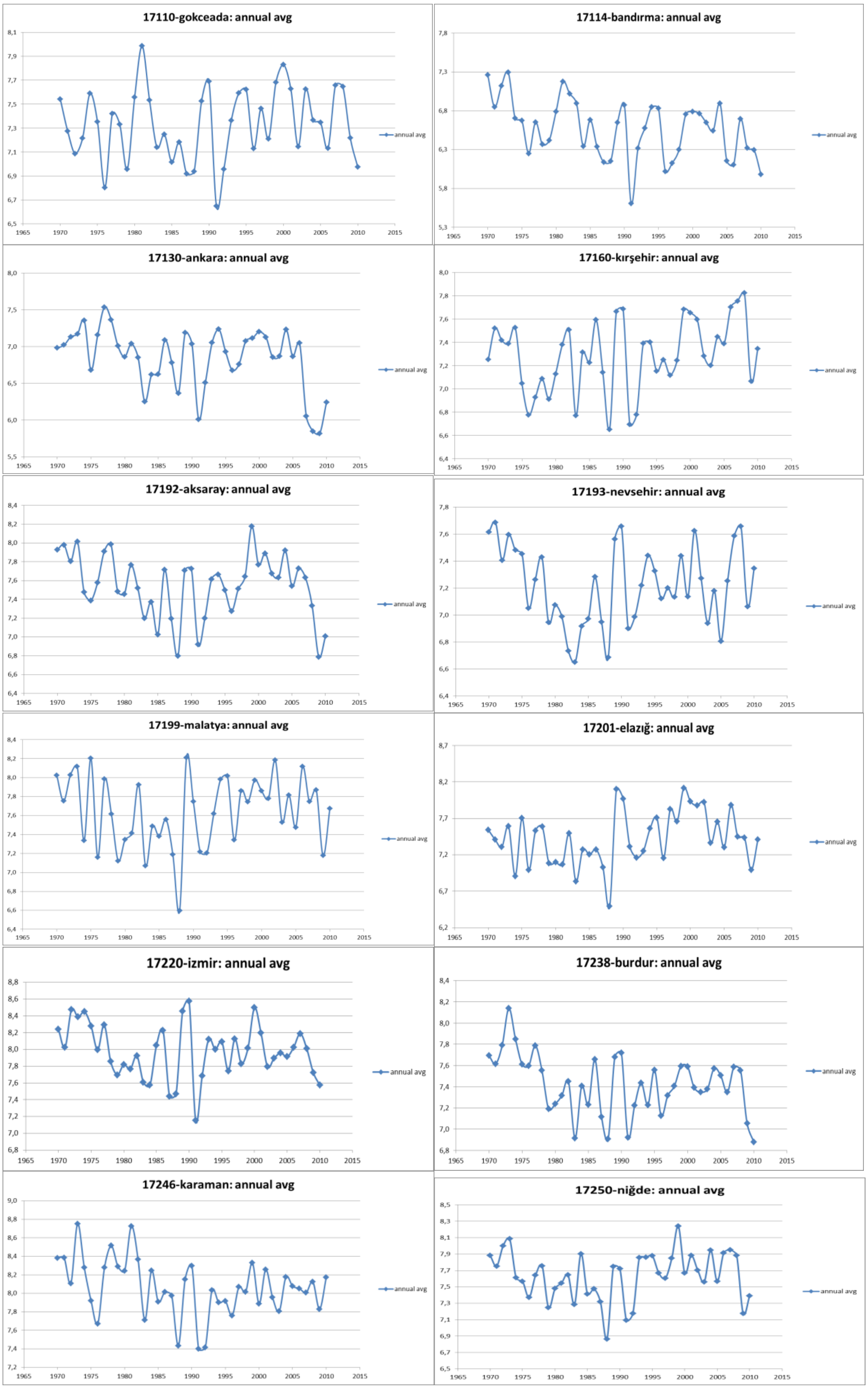
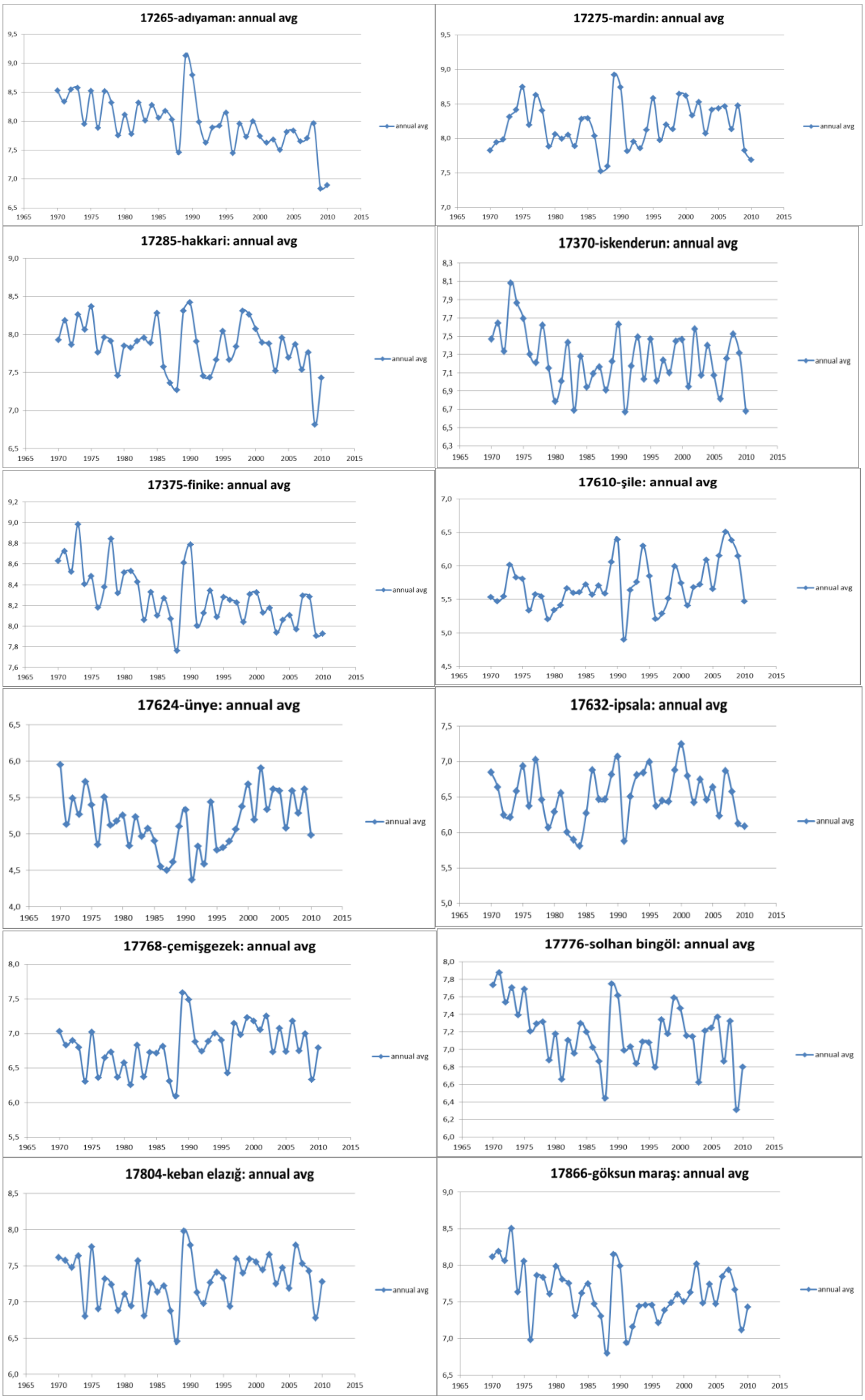


Figure B.1. Cont.



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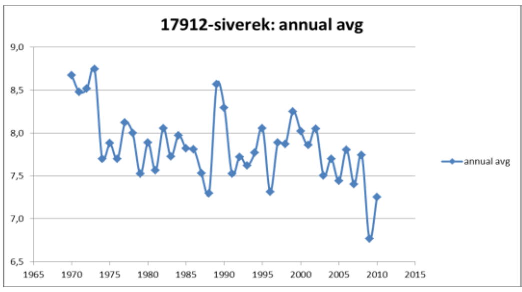

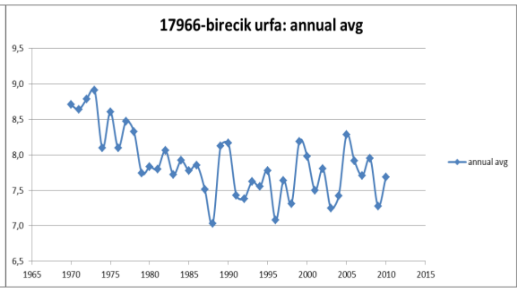

Figure B.1. Cont.

APPENDIX C

GRAPHS OF ALL STATIONS IN ONE FIGURE

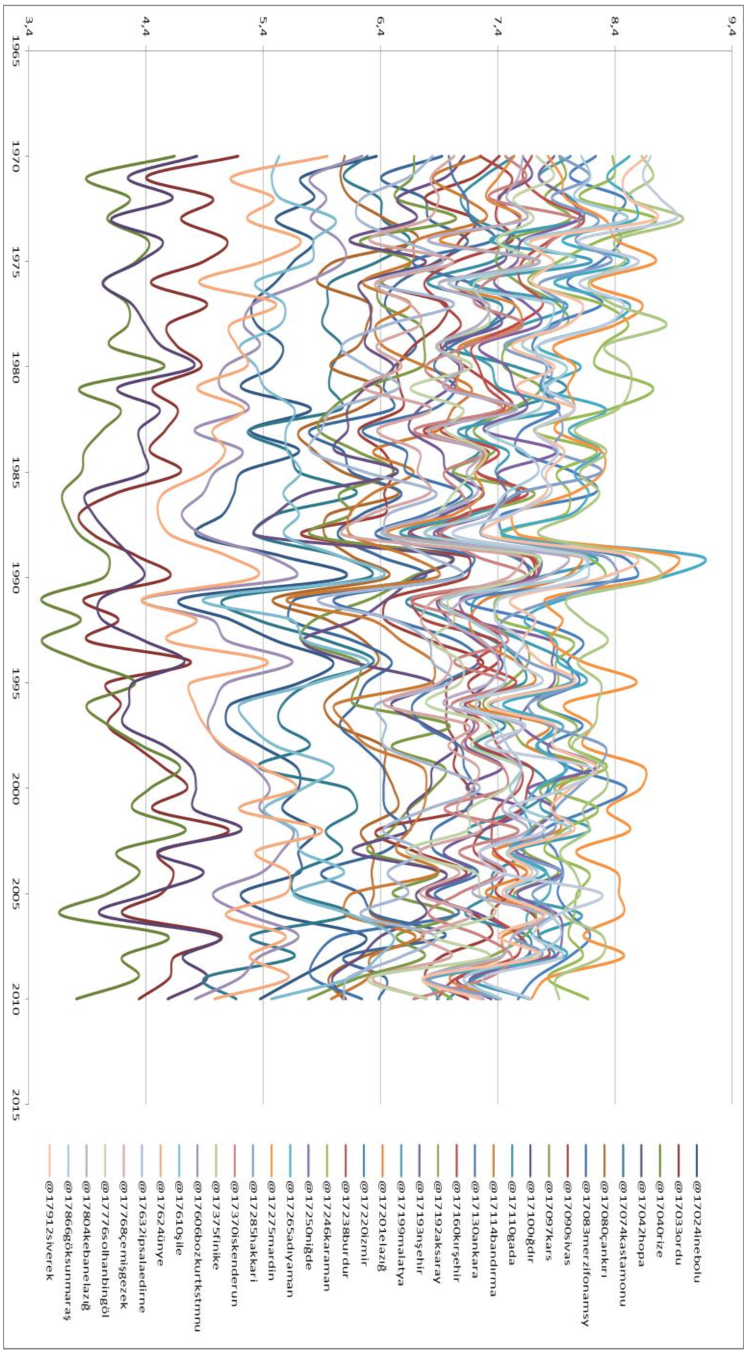

Figure C.1. Graphs of all stations which are determined as homogenous in one figure. Vertical axis represents SD and horizontal axis represents the years.