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Trend analysis of 41 years of sunshine duration data for Turkey

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Abstract: Accurate knowledge of solar irradiation reaching the earth's surface is one of the most important pieces of information to use in global warming studies. In this respect, trend analysis of solar irradiation data for the long term is an essential evaluation method of climate change. Sunshine duration data have been recorded for many years, directly correlated to solar irradiation. Therefore, trend analysis of sunshine duration data is also an important research topic of climate change. Global research from different regions of the earth showed diming (1950s to about 1980s) and brightening (about 1980s to recent years) periods in solar irradiation. The present work aims to obtain the trends of the measured sunshine duration over Turkey. Seasonal and yearly bright sunshine hours of 36 selected stations are used and quite similar trends are seen. A decreasing trend (between 1970 to about 1990) is clearly identified for most of the stations. Nevertheless, the increasing period after 1990 is not so clear; however, we observed either zero trend variation or a reduction in the rate of decrease of sunshine duration for most of the locations. The decreasing period might be attributed to human-induced air pollution.

Key words: Sunshine duration, solar irradiation, global dimming and brightening, trend analysis

1. Introduction

The solar surface radiation (SSR) can be defined as the sum of the direct and diffuse radiation incident on the surface. There are many studies in the literature that claim that SSR incident on the earth's surface between the 1950s and about 1980s (roughly between 1980 and 1990) was diminishing, while afterwards it was increasing. Most of these studies were cited and summarized in Wild's review article [1]. This variation is generally in agreement with the trends in independent data sources (regional and global), such as sunshine duration and daily air temperature, as seen in the studies of Stanhill and Cohen [2], Sanchez-Lorenzo et al. [3], Sanchez-Lorenzo et al. [4], and Türkeş et al. [5].

Long-term variations of average solar irradiation reaching the earth have a profound effect on climate change, which in turn affects the agricultural processes, producing environmental and economic impacts. Therefore, it is extremely important to determine accurately the variation of such climatic parameters in the long term. A recent review by Wild [1] covered the evaluations of SSR and other proxy measurements, including sunshine duration (SD), focusing mainly on solar irradiation. Long-term analysis of direct measurements of solar irradiation reveals information on climate change. However, there has not been accumulation of enough data of measurements yet, with instruments having high accuracies and covering a target-oriented area on the earth's

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surface. Therefore, available long-term climatic data that can be tested by statistical means for homogeneity are of crucial importance in understanding climate change issues.

SD is defined as the measure of time (in hours) in which the direct solar radiation is above a certain threshold. This threshold is usually taken as 120 W m^{-2} [3]. SD is a proxy datum used in estimating solar radiation. However, use of measured data in estimating another quantity might mean a reduction of information that it carries, due to the fact that it is a direct measurement, but errors may be introduced in obtaining the correlations. Therefore, direct use of such data may reveal information directly on different aspects of long-term climatic changes. We should here note that the long-term reduction of SD data can be attributed to increasing aerosols and pollution, as this will result in a decrease of sunshine duration readings due to the reduction in the records during the times when the solar irradiation values are close to the threshold values of the recording instruments. Results of the study by Hatzianastassiou et al. [6] on aerosol optical thickness (AOT) in the eastern Mediterranean basin shows evidence for this case and results of that study will be compared to present findings in Section 3.2.

Most of the models/correlations on estimating solar irradiation by SD data are based on early research conducted by Angström [7] and later modified by Prescott [8]. All of these types of estimation schemes were later called Angström–Prescott-type correlations. They have either linear forms or higher-order correlations, but the regression coefficients depend on the atmospheric and climatic conditions of the site of interest [9]. There are a few works on prescribing a physical base, such as those by Prescott [8] and Akinoglu [9], and some obtained quadratic relations in accordance with the physical base, verified to be universal, such as those of Akinoglu [9] and Akinoglu and Ecevit [10]. Trend analysis of the estimated solar irradiation values by an Angström–Prescott type of correlation for Turkey was carried out by Aksoy [11].

SD is essentially defined as the time during which the sun is not obstructed by the clouds (pollution might also be effective, as explained above). Other important properties of this variable is that it is readily available all over the world and has relatively higher accuracies [9]. Thus, in the present research, SD data are directly used to obtain information about its trends during the time period of this study.

There are various studies on long-term evaluation of SD, some with proxy data for estimating solar irradiation and others with direct use of it. Sanchez-Lorenzo et al. [4] analyzed spatial and temporal changes in SD and total cloud cover (TCC) on the Iberian Peninsula. SD and TCC have a highly negative correlation and they showed this correlation in their study. After removing the effect of TCC on SD values, they found negative trends from the 1950s to the early 1980s and positive trends after the early 1980s. They also analyzed 79 series of daily or monthly SD datasets [3] from 7 countries in West Europe, representing almost half of the continent. The trend results of this study revealed obvious consistency with the phenomena known as global diming and brightening. Trends decreased from the 1950s to the 1980s and increased after the 1980s.

Stanhill and Cohen [2] used SD data between 1890 and 2002 in Japan as proxy data for SSR. They identified an average increase of 0.08 W m^{-2} in solar radiation. In addition to this, Stanhill and Cohen [12] used SD values of 106 Weather Bureau stations in the United States as proxy for SSR. About 70 of these stations have SD datasets from between 1891 and 1987. They reached the conclusion that SD databases show little evidence for a significant trend in the 20th century.

Liley [13], on the other hand, used directly the SD data of 207 sites in New Zealand and the South Pacific. Some of these records started from 1905. Liley observed that there was a decreasing trend between the 1950s and 1990s and an increasing trend after the 1990s, in agreement with global identification of dimming and brightening periods.

Kaiser and Qian [14] analyzed the SD data of 200 stations in China and determined that most of the stations had decreasing trends between 1954 and 1998. Trend values were approximately –2% to –3% per decade. Over western and northern China, only a few stations had increasing trends.

There are also studies about the evidence of global diming and brightening in Turkey. Aksoy [11] studied use of the SD of 34 stations in Turkey between 1960 and 1994. These datasets were obtained from the Turkish State Meteorological Service (TSMS). In this study, SSR values were estimated from SD data by using a modified version of the Angström-type equation of Ögelman et al. [15] for monthly averages. The estimated set of SSR data for 34 stations was analyzed by Aksoy and the results were as follows [11]: for most of the stations, yearly averages of SSR values had negative trends in autumn and summer, and most of stations had no trend in winter and spring averages. The numerical value of the trends for the estimated data between 1960 and 1994 were averaged to give a value of –3.4%.

Another study by Aksoy [16] used satellite-based radiation data obtained from US National Aeronautics and Space Administration (NASA) satellite imagery. The data were compared and verified using reliable ground observations. In this study, the NASA Surface Meteorology and Solar Energy dataset of solar irradiation obtained for 85 grid cells between July 1983 and December 2005 was used. Trend analysis of the satellite-derived data was carried out by Aksoy with Mann–Kendall rank correlation tests. Results of these trend tests support the event of global brightening.

Comparison of analysis of temperature datasets with the analysis of SD data is an important point for climatic issues. There are some important studies about temperature variability in Turkey. The study by Türkeş et al. [5] evaluated mean, maximum, and minimum surface air temperatures between 1929 and 1999. For yearly averages of the mean temperature, there were significant warming trends for the Mediterranean and southeastern parts for the period of the study. For winter averages, trends were mostly weak and insignificant. For spring, there was a significant warming trend. For summer averages, there was a warming tendency for the western part, and the rest of the country had cooling trends. For autumn averages, there was a cooling trend in the northern part and in the middle of the eastern part.

The study by Türkeş and Sümer [17] was about diurnal temperature rates (DTRs) between 1929 and 1999. Some of the conclusions of that study that are important for the present work, as follows. First, DTRs decreased for most of the urbanized and rapidly urbanizing regions, except for in winter. However, there was no clear gradient from the west to east or south to north. Second, some of the stations' annual and seasonal DTRs had statistically significant increasing trends; however, these stations were not localized to certain regions in all seasons or annually. Third, summer and autumn DTRs decreased with higher rates than winter and spring.

Another study on temperature, by Erlat and Türkeş [18], showed a general increase in summer and tropical days of Turkey between 1950 and 2010. In addition to this, in the subperiod of 1950–1975, the tendency was cooling, and after 1975, it was warming. These results and those of Kadıoğlu [19], Türkeş [20,21], and Türkeş et al. [22] will be considered in Section 3.2. to support the outcomes of the present study.

The aim of the article is to choose appropriate SD datasets and to assess them in terms of trend analysis, to compare the results with other regional and global studies, and finally to reveal information on climate change. First we give the statistical methods, and in the next section we give extent of our data and introduce briefly the statistical methods of reducing and analyzing these data. Next, in Section 3, we present and discuss our results, including comparisons with other studies. Afterwards, we conclude the article and give some future research prospects.

2. Data and statistical methods

2.1. Homogeneity tests

SD data have been measured since the 1930s by the TSMS in Turkey, but data from before 1970 are not given to researchers due to lack of quality control (this information was obtained from the Meteorological Data Processing Department of the TSMS). Hence, the data from 1970–2010 was obtained from the TSMS. The dataset includes 192 stations and these stations are distributed uniformly throughout Turkey.

The datasets have some missing values, and the preliminary analyses include solving this missing value problem. It was observed that 73 stations had missing values of less than 6%. After a noticeable gap, 7 other stations had around 10% missing values and all others had higher than 30% missing values; they were eliminated from the analysis. Therefore, we have chosen 6% as the threshold for imputation and used those stations for the trend analysis. Thus, 73 stations remained to apply further statistical tests. Moreover, 64 of these 73 remaining station had less than 3% missing values.

Case deletion or substitution of the mean value can be safely done in order to solve the missing value problem when the rate of missing values is less than 5% of the dataset [23]. Most of the station datasets obeyed this rule. However, some of them were at the threshold; therefore, a more complicated statistical method, the expectation maximization (EM) algorithm, was used to impute the missing values. The algorithm was used in IBM SPSS 18. It uses the multivariate EM algorithm method to impute the missing values. That is, while imputing the missing values, both the dataset under consideration and the other datasets are comparatively used.

After the imputation of missing values, the second step is to determine whether each dataset is homogeneous or not. "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" [24, p. 5–1].

Meteorological datasets may have some nonmeteorological or nonclimatic errors.

These can be caused by the instrumentation, coding, or processing. These include 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 changes and some cause gradual changes. For instance, replacing instrumentation with new ones may cause abrupt change, while urbanization around a station causes gradual changes [24].

In determining the homogeneity of a dataset, one should first start with metadata analysis (station archives) before application of the statistical methods [24]. Station archives contain information on location and relocation of the station, change of the instruments, calibration of the instruments, etc. However, the metadata tables of the TSMS were not adequate for making a good assessment. Therefore, investigation of the station archives was skipped, and, investigating the data, we reached the conclusion that the tests that we would perform would reveal any problems arising due to metadata.

It is in principle true that the application of statistical tests of homogeneity can identify any abrupt changes in SD data. Sneyers [25] proposed use of the nonparametric Kruskal–Wallis test and Wald–Wolfowitz runs tests because SD data do not follow a well-shaped probability distribution on a yearly base. For normal probability distributions, the parametric methods work well, but if the probability distribution curve is not preassumable, nonparametric methods work well [24]. In this study, we used both of the 2 nonparametric tests and a subjective assessment was also carried out.

The Kruskal–Wallis test is a nonparametric test. It mainly tests whether a single distribution of a station (yearly SD in our case) originates from the same distribution or not [26]. That is, the null hypothesis is that all groups originate from the same distribution. If the null hypothesis is rejected, then it should be concluded that the dataset is not homogeneous. In the analysis, the $\alpha = 0.05$ level of significance is used as it is the generally proposed value for a testing criterion. This value corresponds to a critical K-value (K_c) of 14.067 for 7 degrees of freedom. For example, for the dataset of İnebolu, the K-value was determined to be 13.176, and so it was homogeneous.

Another nonparametric test is the Wald–Wolfowitz runs test for randomness. A subsequent departure of the data values from the mean of the dataset might mean that the set is inhomogeneous. This test determines whether the dataset is random or not with respect to the median or average [27]. A run is defined if a series of values within the dataset is above or below the mean (or median) of the dataset. Test statistics determine the randomness by using these runs. The null hypothesis of this test is that the sequence was produced in a random manner.

Both of the tests have disadvantages and advantages depending on the datasets under consideration. Therefore, after applying both of the tests, depending on the natural variations of the SD data, we decided to use 36 stations out of 192. The details of the decision process are given in [28]. It should be noted that the plots of all years' SD values were also investigated in deciding to choose a dataset for further trend analysis. The plots for 2 such sets to which we applied the trend analysis are given in Figure 1.

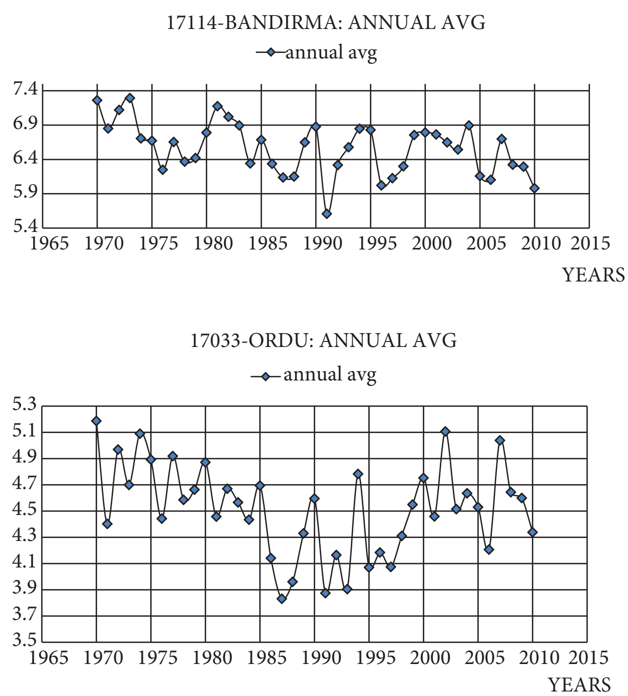

Figure 1. SD variation of 41 years for Bandırma and Ordu.

The stations that were assessed as homogeneous are located on a map in Figure 2 and are also given in Table 1 (total: 36 stations). We note that the stations determined as homogeneous are quite evenly distributed all over the land area and also they are representative of different climates of Turkey. Therefore, they can represent the overall characteristics of SD data trends of the whole country.

Table 1. Results of homogeneity tests. The stations passing the tests are represented by '1'. K-W: Kruskal–Wallis test.

Code	Station	K-W	K value	Runs	Z value	Missingness % before imputation
17022	Zonguldak	0	18.913	0	–2.212	1.1
17024	İnebolu	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	Iğdır	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	İzmir	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	Isparta	0	20.524	0	–2.845	0.2
17246	Karaman	1	12.297	1	–0.629	1.6

Table 1. Continued.

Code	Station	K-W	K value	Runs	Z value	Missingness % before imputation
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	İskenderun	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	İpsala-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-K.maraş	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

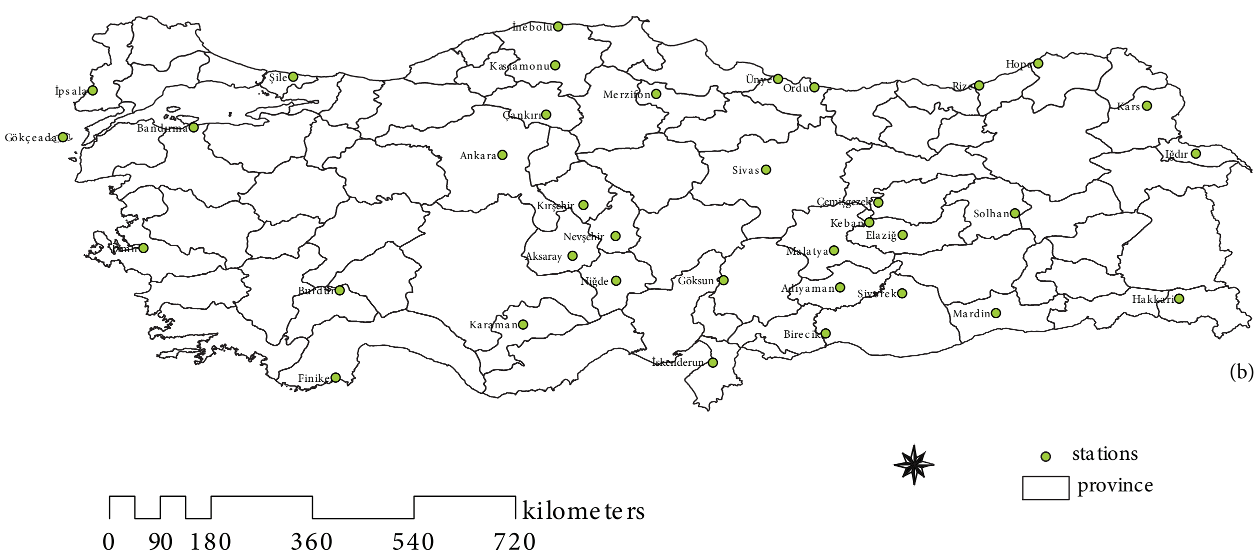

Figure 2. The stations that were determined to be homogeneous.

2.2. Trend analysis

After the homogeneity considerations, we used Mann–Kendall trend test analysis as it is widely used in the investigations of climatic data. This test is a rank-based test similar to the Kruskal–Wallis test and it is also known as Kendall's τ statistic [29]. There are 2 main reasons for choosing the rank-based tests: they are robust to datasets that have extreme values and they exhibit good performance for datasets with skewed variables.

For the Mann–Kendall trend test, the null hypothesis is that the dataset is randomly distributed through the years. In other words, there is no trend in the dataset. The null hypothesis should be rejected if the absolute value of z is larger than 1.96 where the level of significance is taken as $\alpha = 0.05$. If it is rejected, a positive S (test statistics) means an increasing trend and a negative S means a decreasing trend. For this test analysis, the P-value approach may also be used.

After investigating the dataset using the plots, it was observed that there was a change in trends around the year 1990 for most of the station. Therefore, we divided the years of the dataset into 2 parts and the year of division was around 1990 for all of the dataset. Aksoy [11] and Aksoy [16] showed the diming and brightening periods in Turkey and, in those works, the start of the brightening period was also determined to be around 1990. Therefore, we decided to divide the dataset into 2 parts as the decreasing trend period, from 1970 to around 1990, and the increasing trend period, between around 1990 and 2010. Mann–Kendall trend analysis was also applied to all datasets of the years 1970–2010. We also carried out seasonal trend analysis to reach conclusions on possible anthropogenic contributions or some other factors of the climatic variations.

3. Results and discussion

3.1. Results of the trend analysis

Sen's slope of trends (slope of the trend lines with a nonparametric algorithm) of each station is given in Table 2, P-values of trend analysis are given in Table 3, and overall trend results are tabulated in Table 4. The years of dividing the data into decreasing and increasing trend periods are also given. The numbers 1 or 2 following the word "annual" and the names of seasons are to indicate the decreasing (1) and increasing (2) periods. The last columns without indicative numbers are the results for the trend analysis of all years' datasets. Figures 3–5 depict the yearly and seasonal results of the trend analysis of the maps of Turkey.

Most of the sites (22 sites) had no significant increasing or decreasing trends if the whole years' datasets were considered (Table 4, last columns). This result was expected because all data between 1970 and 2010 were used, such that the decreasing trends before around 1990 were partly canceled by the years of the increasing trend period after 1990 and, therefore, dimming and brightening periods cannot be differentiated. In other words, the decreasing amount in the first period could be partially compensated for by the increasing amounts in the second period. However, there was a remarkable negative trend (Figure 3) in the southeastern part of Turkey, which is probably the reason why a clear identification of the increasing trend period was not observed. Trends of 7 sites (Adıyaman, Hakkari, Solhan, Göksun, Birecik, and Siverek) were negative between 1970 and 2010 (especially during summer; see Figure 3, summer). According to the recent climatic classification by Iyigun et al., these regions are Dry Summer Subtropical Semihumid/Semiarid Continental Mediterranean (region 6), Semihumid Cold Continental Eastern Anatolia (region 7), and Semihumid Continental Mediterranean to Eastern Anatolia Transition (region 14) [30]. This may be an indication that these regions of the Anatolian peninsula are more sensitive to climate changes than other parts. Two sites in the central part of the country (Karaman and Burdur) also had negative trends. As can be seen from Figure 3, the other 5 stations that had either negative or positive significant trend results were not from a particular region but rather were evenly distributed.

Table 2. Sen's slope of trends of each station. Cells are written in bold if the result is significant. Significant results have P-values of less than 0.05.

Station number	Name of station	Beginning of period 2	Winter 2	Spring 2	Summer 2	Autumn 2	Annual 2	Winter 1	Spring 1	Summer 1	Autumn 1	Annual 1	Winter	Spring	Summer	Autumn	Annual
17024	İnebolu	1989	−0.02076	**0.048984**	0.025516	−0.00191	0.012104	−0.03743	−0.03716	**−0.06244**	−0.02173	**−0.04897**	−0.00226	0.020705	−0.00166	−0.00739	−0.00035
17033	Ordu	1988	0.011222	**0.034435**	**0.057523**	6.91E-05	**0.026441**	**−0.04692**	−0.03208	−0.05002	−0.02029	**−0.04295**	**−0.02034**	0.004039	0.000779	**−0.01483**	−0.00779
17040	Rize	1992	0.023121	−0.00124	0.032502	0.007455	0.018315	**−0.04956**	−0.01708	−0.01517	−0.02507	**−0.03038**	−0.00763	−0.00156	0.008578	−0.00036	0.00028
17042	Hopa	1987	**0.027266**	0.016615	**0.068255**	0.002196	**0.032552**	−0.02801	−0.0269	0.012661	−0.00879	−0.01305	−0.00395	0.012975	**0.022405**	0.007532	**0.010357**
17074	Kastamonu	1991	−0.02471	0.012779	−0.01324	−0.03511	−0.01458	−0.01597	−0.03525	−0.03046	**−0.04939**	**−0.03612**	−0.01096	−0.00923	−0.02376	**−0.02836**	**−0.01774**
17080	Çankırı	1992	−0.03486	0.03373	**0.066495**	−0.02307	0.005897	0.007565	−0.01507	−0.03199	−0.02848	−0.01191	0.003883	0.015993	0.00204	−0.00329	0.00484
17083	Merzifon-Amasya	1991	−0.0053	**0.049885**	0.050778	0.004412	0.021081	−0.01335	−0.02533	−0.05465	−0.03525	**−0.0346**	−0.01153	−0.00183	−0.00852	**−0.01707**	**−0.01031**
17090	Sivas	1989	0.014732	0.019812	−0.00872	0.001792	0.005437	**−0.06142**	**−0.05626**	**−0.05768**	**−0.07886**	**−0.0589**	0.002201	0.014811	0.005056	−0.00637	0.003816
17097	Kars	1989	0.017141	**−0.01551**	0.017599	0.029896	0.002901	**−0.07344**	−0.01793	−0.03004	**−0.06039**	**−0.03975**	0.011557	0.006273	−0.00784	−0.00809	−0.00142
17100	Iğdır	1989	−0.03652	**−0.04301**	0.005343	0.017599	−0.01414	**−0.05921**	**−0.04778**	**−0.04957**	**−0.08112**	**−0.06959**	−0.0014	0.00123	−0.00607	0.002576	−0.00165
17110	Gökçeada	1989	−0.03027	0.026383	0.032708	**−0.02358**	8.34E-05	−0.01442	−0.01717	−0.02226	−0.00678	−0.01842	0.004743	0.014263	0.007404	**−0.01171**	0.002936
17114	Bandırma	1992	−0.03095	0.009205	−0.03746	**−0.04248**	−0.01538	−0.03199	−0.0306	**−0.05511**	−0.04084	**−0.03688**	−0.01307	0.003507	**−0.01995**	**−0.02745**	**−0.01294**
17130	Ankara	1992	−0.03855	−0.02124	−0.04661	**−0.04746**	−0.03089	−0.00932	−0.02299	**−0.05872**	−0.02951	−0.02719	−0.00332	−0.00365	**−0.02696**	**−0.0191**	−0.01018
17160	Kırşehir	1992	0.054346	0.024434	0.024638	0.001981	0.021479	−0.02048	−0.00347	0.01065	−0.01693	−0.0017	0.00748	**0.016841**	0.000958	0.005721	0.00818
17192	Aksaray	1992	0.000827	0.001876	−0.00445	−0.0403	−0.0035	**−0.05866**	−0.02815	−0.01098	**−0.05051**	**−0.03475**	0.001265	0.005398	−0.01089	**−0.02095**	−0.00598
17193	Nevşehir	1989	0.003961	−0.00118	−0.00341	−0.00394	0.001248	**−0.06896**	−0.02983	−0.02701	**−0.06897**	**−0.05033**	−0.01147	0.009808	0.005646	**−0.01173**	−0.00191
17199	Malatya	1989	−0.01907	−0.00911	−0.02002	0.033658	−0.00224	−0.05684	−0.01883	**−0.0436**	**−0.06943**	**−0.04725**	0.011869	0.008954	**−0.02525**	0.005804	0.001851
17201	Elazığ	1989	−0.01532	−0.00865	−0.02493	0.014474	−0.00698	0.003357	−0.03396	**−0.03492**	−0.02581	−0.02072	0.016094	0.009302	−0.00686	**0.013534**	0.008699
17220	Izmir	1989	−0.01936	−0.00825	**−0.0241**	−0.00536	−0.01061	**−0.09513**	−0.03253	−0.01839	−0.03522	**−0.04441**	−0.00499	0.003006	−0.005	**−0.01495**	−0.00701
17238	Burdur	1989	−0.01963	0.007476	−0.00799	−0.00239	−0.00423	**−0.07331**	**−0.06083**	−0.02233	−0.02917	**−0.04323**	−0.0045	−0.00214	**−0.01652**	**−0.01212**	**−0.00757**
17246	Karaman	1989	0.018084	0.02176	0.0051	−0.00099	0.007648	−0.02581	−0.02997	−0.01427	−0.04716	**−0.02627**	−0.01325	0.004489	−0.00476	**−0.01922**	**−0.00804**
17250	Niğde	1989	0.009157	−0.0029	0.008507	−0.00749	0.003621	−0.03952	−0.01765	−0.01972	**−0.05702**	**−0.03479**	0.005867	0.004914	−0.00171	−0.00563	0.002161
17265	Adıyaman	1989	−0.07772	−0.0572	**−0.0416**	**−0.03534**	**−0.0372**	−0.04796	−0.02663	**−0.02648**	−0.02952	**−0.03121**	−0.01818	−0.01334	**−0.03639**	**−0.02774**	**−0.02302**
17275	Mardin	1989	−0.01742	−0.00823	−0.01324	−0.00123	−0.00871	−0.06527	−0.01134	−0.00677	−0.02853	−0.01584	−0.00205	0.012197	0.000841	−0.0026	0.004058
17285	Hakkari	1989	−0.01347	−0.05963	**−0.04339**	−0.01337	**−0.02569**	−0.0559	0.002899	−0.0306	**−0.04195**	**−0.03336**	−0.00633	−0.00449	**−0.01701**	−0.00841	**−0.00911**
17370	Iskenderun	1989	−0.02365	−0.00877	0.006272	0.006419	−0.00776	**−0.07555**	**−0.05412**	0.007706	**−0.04544**	**−0.04416**	−0.00431	−0.0007	−0.0106	**−0.01475**	−0.00833
17375	Finike	1989	**−0.06315**	0.00681	**−0.0138**	−0.01545	**−0.01773**	**−0.03808**	**−0.06784**	−0.02866	−0.02855	**−0.03589**	−0.00887	−0.00303	**−0.02458**	**−0.01632**	**−0.0141**
17610	Şile	1991	0.021468	0.063798	0.071377	−0.00721	**0.041245**	0.003997	0.020101	0.017927	−0.00014	0.010323	0.006033	**0.021529**	0.015512	−0.00353	**0.009839**
17624	Ünye	1988	0.017151	**0.049767**	0.036133	0.02297	**0.037808**	**−0.05951**	**−0.07117**	−0.06678	−0.03191	**−0.0558**	−0.01028	0.013709	0.004244	0.000376	0.002268
17632	İpsala-Edirne	1991	−0.03954	0.00795	−0.00119	**−0.04126**	−0.01489	−0.00969	0.010028	−0.02189	−0.00367	−0.0027	0.005799	0.011467	0.00516	**−0.0157**	0.000772
17768	Çemişgezek	1989	−0.01985	−0.01964	−0.01213	−0.01912	−0.0133	−0.02651	0.002168	−0.01196	−0.041	**−0.02245**	0.009847	**0.025412**	0.005471	−0.00525	0.007167
17776	Solhan-Bingöl	1989	−0.01742	−0.05033	−0.00229	−0.00916	−0.01584	**−0.1064**	−0.04357	−0.01211	**−0.06717**	**−0.05267**	−0.00734	−0.00737	**−0.01708**	**−0.01289**	**−0.01218**
17804	Keban-Elazığ	1989	−0.03554	−0.01992	−0.00842	0.021132	−0.0063	−0.03944	−0.03571	**−0.0173**	**−0.04201**	**−0.0403**	0.008985	0.012695	−0.00523	−0.00326	0.003128
17866	Göksun-K.maraş	1989	−0.02756	0.022871	0.022224	0.000506	0.009585	−0.03613	−0.034	**−0.07729**	**−0.04599**	**−0.04796**	−0.00683	0.007249	**−0.01877**	**−0.02309**	**−0.01085**
17912	Siverek	1989	−0.0367	**−0.048**	**−0.03591**	−0.0097	**−0.03164**	**−0.06698**	−0.01077	**−0.03988**	**−0.05529**	**−0.05349**	−0.0158	−0.00593	**−0.01971**	**−0.02245**	**−0.01597**
17966	Birecik-Urfa	1989	−0.00367	−0.01147	−0.00951	0.008149	0.002466	**−0.08751**	**−0.06828**	**−0.08715**	**−0.07687**	**−0.07572**	−0.00478	−0.01544	**−0.05501**	**−0.0176**	**−0.02391**

Table 3. P-values of trend analysis.

Station code	Name of station	Division year	Winter 2	Spring 2	Summer 2	Autumn 2	Annual 2	Winter 1	Spring 1	Summer 1	Autumn 1	Annual 1	Winter	Spring	Summer	Autumn	Annual
17024	İnebolu	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	Çankiri	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	Iğdır	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	İskenderun	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-K.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

Table 4. Trend results of each station '0' denotes no significant trend, '+' denotes significant positive trend, and '-' denotes significant negative trend.

Station code	Name of station	Division year	Winter 2	Spring 2	Summer 2	Autumn 2	Annual 2	Winter 1	Spring 1	Summer 1	Autumn 1	Annual 1	Winter	Spring	Summer	Autumn	Annual
17024	İnebolu	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	Iğdır	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	İzmir	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	İskenderun	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	İpsala-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-K.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	–	–	–

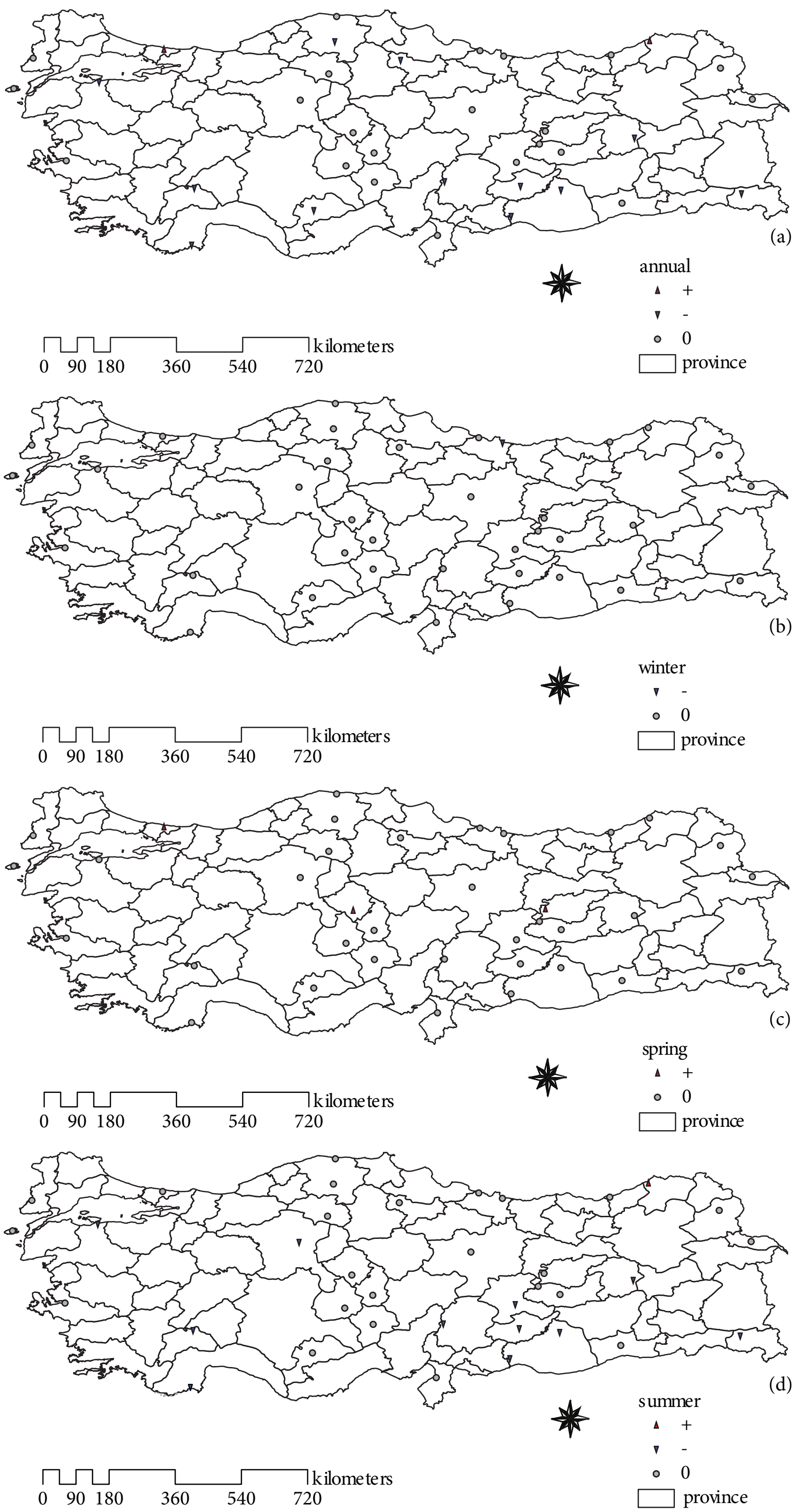

Figure 3. Results of trend analysis between 1970 and 2010 for a) annual, b) winter, c) spring, d) summer, and e) autumn averages.

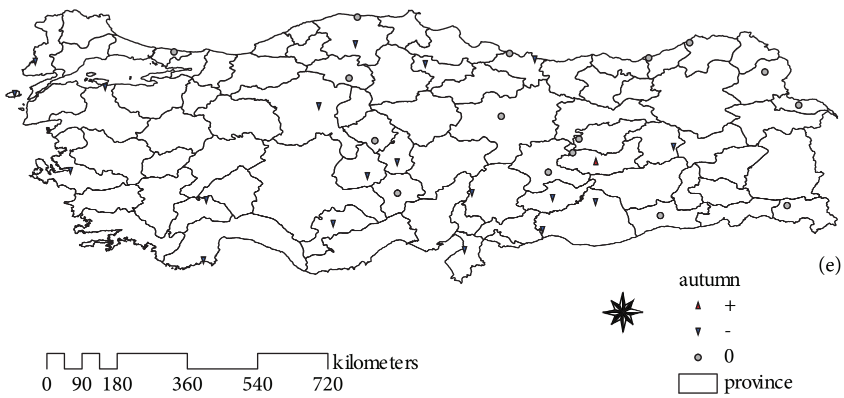

Figure 3. Continued.

The trends for the winter month averages were zero, except for 1 location: Ordu. This might be attributed to the increase in the rainfall. For spring averages, only 3 sites had significant trend values, and they were positive. These sites were not from a particular region. Similarly, for the summer averages, most of the sites had no significant trend value; however, there was a negative trend at in the southeastern part of Turkey (Adıyaman, Malatya, Göksun, Solhan, Birecik, Siverek, and Hakkari). About half of the sites (19 stations) had negative trend values for autumn averages. Two of them were in the northwestern part of Turkey (Gökçeada

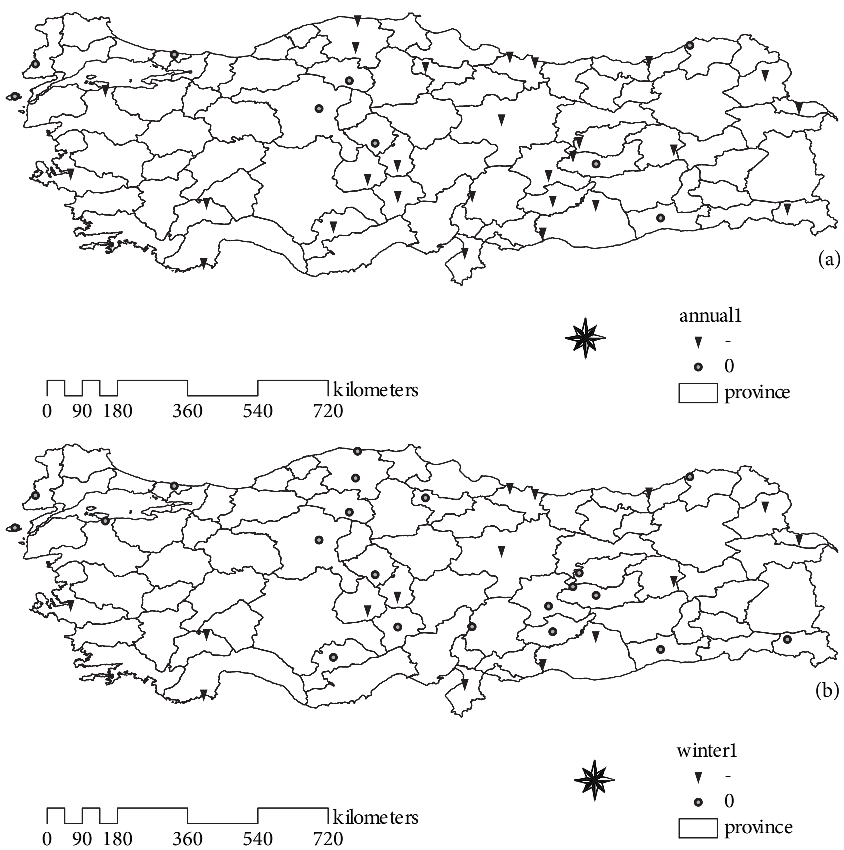

Figure 4. Results of trend analysis between 1970 and around 1990 for a) annual, b) winter, c) spring, d) summer, and e) autumn averages.

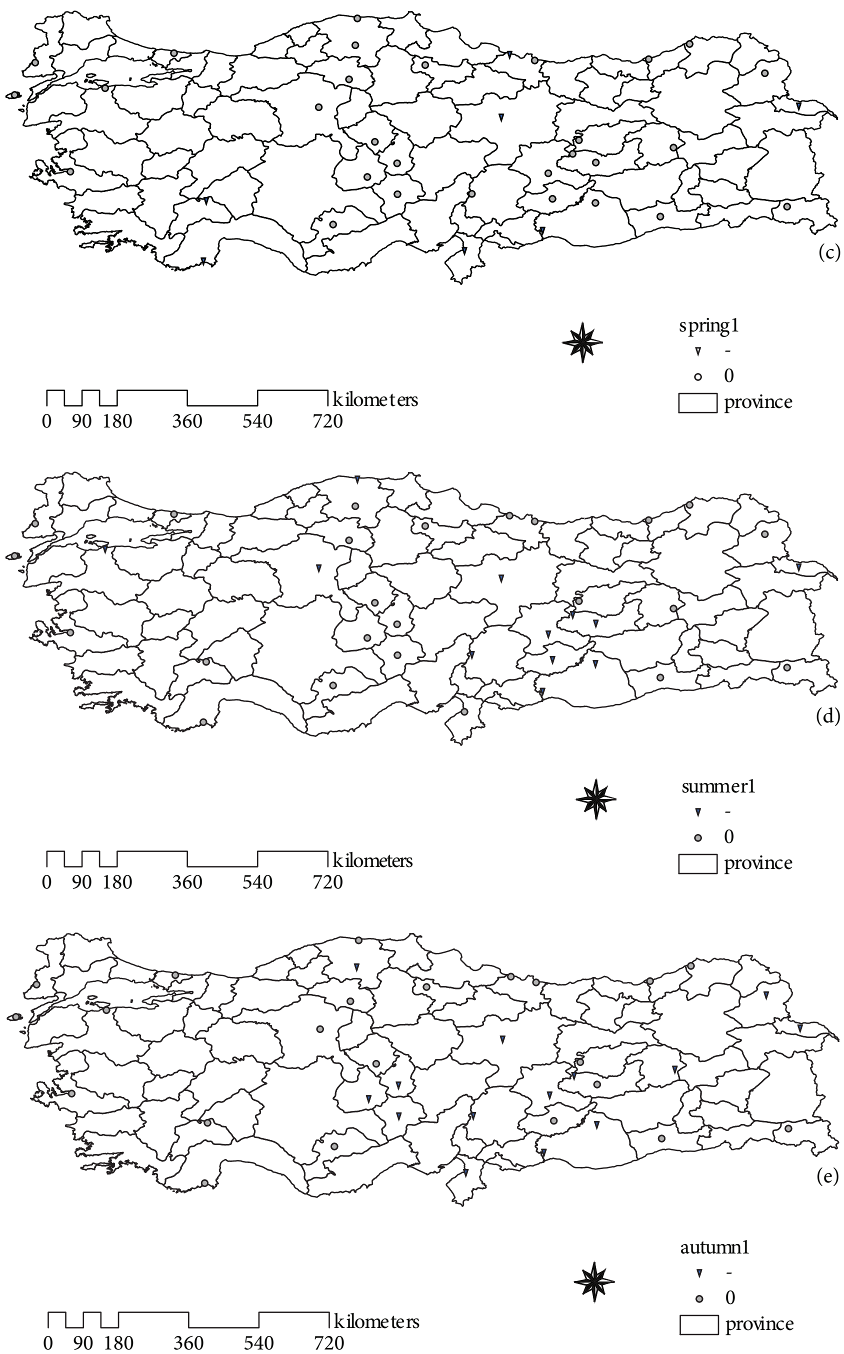

Figure 4. Continued.

and Bandırma), 5 of them in the center of the country (Ankara, Nevşehir, Aksaray, Burdur, and Karaman), and 6 of them in the southeastern part of Turkey (Adıyaman, Malatya, Göksun, Solhan, Birecik, and İskenderun). Hence, we can state that for the regions where negative trend were obtained, the reason is mostly the negative trends of the autumn months, when all years' datasets are considered. For the southeastern region, the negative trends of the summer months are also effective.

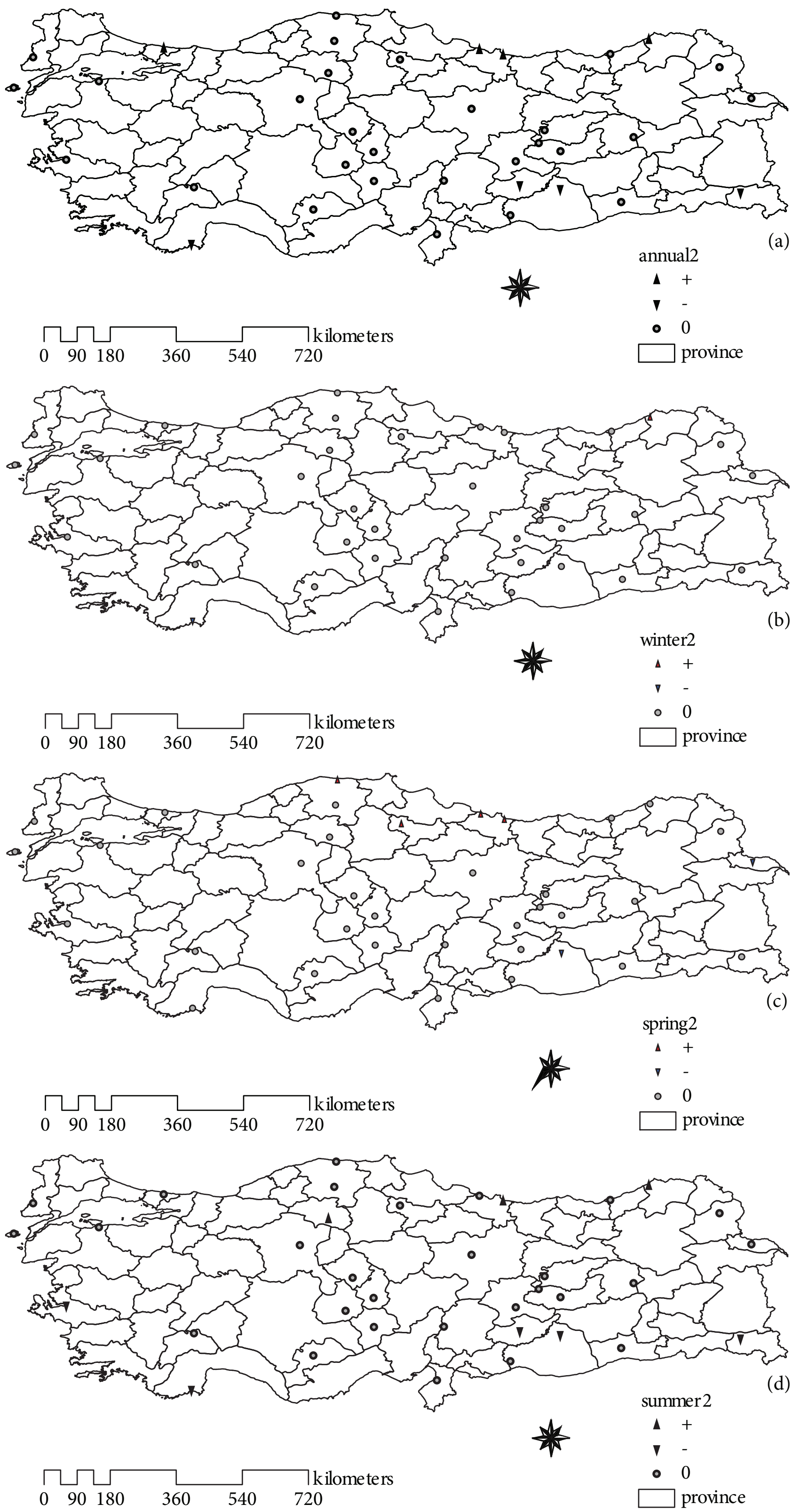

Figure 5. Results of trend analysis between around 1990 and 2010 for a) annual, b) winter, c) spring, d) summer, and e) autumn averages.

Trend analysis of SD values from 1970 to around the 1990s of all the sites is in agreement with the global dimming period (Table 4; Figure 4). For the yearly averages, 27 of the sites have negative trends and the remaining 9 sites have no trends. The sites that have no trend are not localized to a particular region of the country. The average of the Sen's slope (slope of the trend lines) of 27 sites is –0.043, which means that the average decrease of SD of these sites is –4.3%. The average Sen's slope of all the sites is –0.035, giving a –3.5% decrease in SD values (Table 2). This result is in a good agreement with Aksoy's results [11]. We should note that the value is less reliable as it considers all of 36 locations. However, the trends of 27 stations were determined not only by considering the Sen's slope but also by taking P-values into account. Table 2 gives the Sen's slope for the Sen's trend lines for all 36 locations and for all periods of investigations. We also present the P-values in Table 3 because the algorithm excludes the dataset having P-values larger than the chosen level of significance (0.05) and hence the obtained trends are more reliable. That is, we can safely state that the average value of the negative trend rate, –4.3%, for 27 stations clearly verifies the global dimming period.

For the winter averages of the dimming period, 21 of the sites had no significant trend and 15 of them exhibited significant negative trends. These 15 sites were not from a particular region. For the averages of the spring months, only 7 of the sites had significant negative trends, while the remaining 29 sites had no trends. Similarly, these 7 sites were not localized to a particular region. For the summer averages, 12 of the sites had significant negative trends and the remaining 24 sites had no significant trend. Seven of these 12 sites were localized in the southeastern part of Turkey (Malatya, Elazığ, Adıyaman, Birecik, Siverek, Göksun, and Keban). The reason for this localization might be clarified using analysis of different climatic parameters. For autumn averages, 14 of the sites had significant negative trends and the remaining sites had no trend. Two of the sites that had negative trends were in the eastern part of Turkey (Kars and Iğdır), 4 of them in the central part of Turkey (Sivas, Aksaray, Nevşehir, and Niğde), and 6 of them in the southern part of Turkey (Birecik, Siverek, Göksun, Keban, Solhan, and İskenderun). Negative trends mostly occurred during winter and autumn, which might be attributed to increases in air pollution [11].

A clear overall increasing trend could not be observed in the trend analysis of SD values from around 1990 to 2010 (Table 4; Figure 5). The analysis for yearly averages revealed that 4 of the sites in the northern part of Turkey had positive trends (Şile, Ünye, Ordu, and Hopa). Four of the sites had significant negative trends, 3 in the southeastern part (Adıyaman, Siverek, and Hakkari) and 1 in the southern part of Turkey (Finike). The remaining sites had no significant trends. For these regions, in the period from about 1990 to 2010, we might conclude that, although a number of locations had negative trends, the rate of diming was considerably smaller (see Table 2) and most sites had no trend at all.

For winter averages, 34 of the sites had no significant trends and only 2 sites (Finike and Hopa) had significant trends. For the spring averages, 4 of the sites had significant positive trends, and 3 of them are in the northern part of Turkey (İnebolu, Ordu, and Ünye). Two of the sites from different regions had negative trends and the remaining 30 of the sites had no significant trends. For the summer averages, 3 of the sites had positive trends and 2 of them were again at the northern part (Ordu and Hopa), while 5 of the sites had significant negative trends and 3 of them are in the southeastern part (Adıyaman, Hakkari, and Siverek). For autumn averages, only 5 of the sites had significant negative trends and the others had no trend. Three of these 5 sites were in the northwestern part of Turkey (Gökçeada, Bandırma, and İpsala). The remaining 31 of the stations had no trends. Thus, seasonal investigations support that the negative trends had 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.

Trends of each station for annual, winter, spring, summer, and autumn averages are given in Table 4 where '0' represents no significant trend, '+' represents a significant positive trend, and '–' represents a significant negative trend with $\alpha = 0.05$ level of significance. In the columns, '1' denotes the period from 1970 to around 1990, '2' denotes the period from around 1990 to 2010, and if the column has no number, it denotes the period between 1970 and 2010.

3.2. Discussion

Aksoy [11] also studied the SD values of Turkey for 34 stations between the years 1960 and 1994. Aksoy used SD data as a proxy to calculate SSR by using a modified version of Ögelman's equation [15], which was summarized here in Section 1. Aksoy also used linear regression equations to analyze the trends of the datasets and found a diming trend with a value of –3.4% in the mentioned period. Most of the sites of Aksoy's study were different than those in the present research, and also the time periods do not overlap completely. However, the concurrence in diming is remarkable although the result is slightly different. After the tests of the present study, we can state that the dimming was more clearly detected because the average rate of decrease of 27 stations that passed all the tests in this study was higher at –4.3%.

As mentioned in Section 1, Aksoy [16] also studied satellite-based radiation data at the surface of the earth taken from NASA. In that work, Turkey was divided into 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 trends; that is, 73% of the grid cells had positive trends and 27% had no trend. Most of the increasing trends began in the period 1995–1997, and for a considerable number of sites, brightening began in 1991. It is obvious that there is no clear agreement between the results of Aksoy [16] and this study for the period of brightening. However, we should note that this study is an application of the tests directly to an indirect parameter, i.e. the bright sunshine hours, and, nevertheless, in the present work there is still a less clear agreement about the global brightening period.

Comparing air temperature with SD data can be meaningful. Studies by Erlat and Türkeş [18,20,21] and Türkeş et al. [22] indicated negative trends between the late 1960s and early 1990s for air temperatures. One of the main results of Türkeş' investigations is that the minimum annual air temperature has an increasing trend after 1990s. This is in accord with Aksoy's results of satellite-derived data and partially agrees the results of the present study.

The study by Kadıoğlu [19] also investigated the trends in surface air temperature data over Turkey for 17 stations between 1939 and 1989. A warming trend was observed between 1939 and 1989 and cooling trend between 1955 and 1989. The average trend values of maximum, minimum, and mean temperature measurements were negative for 17 stations between 1955 and 1989. Especially for the northern part of Turkey, the negative trend is much more remarkable. The cooling trend of this period is in concurrence with the trend of SD values from 1970 to around 1990 in the present work. A statistical comparison is needed to compare temperature and SD measurements more accurately; however, that statistical comparison is beyond the scope of this study.

Aerosol variations are also important for SD variations. The most probable reasons for variations of SD and SSR values are related to atmospheric aerosols. Aerosols can affect SD and SSR directly or indirectly by modifying cloud formation [1]. Hatzianastassiou et al. [6] studied spatial and temporal variation of AOT in the eastern Mediterranean basin. They showed that dust coming from North Africa (and especially from the Sahara Desert) modified the AOT. Due to this reason, they concluded that AOT decreases towards the north. Results of trend analysis showed that after the 1990s the northern part of Turkey had a positive trend but the southern part had a negative trend. Thus, our result of an increasing trend in the northern coastal Turkey can be explained by the arguments of Hatzianastassiou et al. obtained for East Mediterranean basin.

4. Conclusions

Datasets of daily values of bright SD for 192 stations were obtained from the TSMS from between 1970 and 2010. After missing value and homogeneity analysis, 36 of the stations were determined to be homogeneous. Trends of these 36 stations were analyzed by the Mann–Kendall trend test. There was a remarkable decreasing trend of SD values between 1970 and around 1990, especially in yearly averages. In general, the negative trend after around 1990 did not continue; moreover, it turned into a positive trend in the northern coastal area. The results of the period from 1970 to around 1990 are clearly in agreement with the global phenomenon known as global diming and brightening and agree also with the results of Aksoy's study [11]. However, the results of the period between around 1990 and 2010 are not clearly in concurrence with global brightening, but it is observed that after about 1990, either there was no increasing or decreasing trend or the rate of decrease was considerably reduced.

For the dimming period, the results of the present work are in agreement with the SD study of Aksoy [11] and agree partly with the brightening period of satellite studies conducted by Aksoy [16]. The air temperature trends obtained by Kadıoğlu [19], Türkeş [20,21], and Türkeş et al. [22] between the late 1960s and early 1990s are also in good agreement with the findings of the present research.

Results of the study by Hatzianastassiou et al. [6] are important in explaining the difference in trend values between the north and the south after the 1990s. Their study covered the years 1980–2005. In the present study, a similar situation was observed as the brightening increased in the northern regions for Turkey. The northern part of Turkey had positive trends and the southern part had negative trends since the northern part is farther than the southern part from North Africa, from where the desert dusts originate. A detailed analysis and discussion on the transport of Sahara Desert sand and effects on the human environment and plants in Turkey appeared recently [31].

Although cloudiness is important for SD, its temporal (daily, seasonal, yearly) variation is very high compared to the seasonal and yearly average SD trends. Another fact is that the correlation between cloudiness and SD is low even for average values, as shown by Aksoy [32] and Sezen at al. (unpublished conference proceeding in Turkish: Sezen I, Sakarya S, Topcu S, Aksoy B, İncecik S. Türkiye'nin Marmara ve Güneydoğu Anadolu Bölgeleri için 2011'deki açık günlerdeki global güneş radyasyonunun değişiminin açıklık indeksi ile incelenmesi. In: 6. Atmosfer Bilimleri Sempozyumu. İstanbul Technical University, İstanbul, Turkey, 2013). An additional problem is as follows: cloudiness data are taken by visual inspections 3 times a day; that is, these data are rather rough for revealing low trends within the periods of such studies. We also note that even on clear days the SD can vary considerably from day to day because of variations in relative humidity and aerosols, as noted by Aksoy [32] and Aksoy (unpublished conference proceeding in Turkish: Aksoy B. Türkiye'de son güneş tutulmasındaki güneşlenme süresi ölçümlerinde nemin etkisi. In: IV Yenilenebilir Enerjiler Sempozyumu ve Sanayi Sergisi. Ege University Solar Energy Institute, İzmir, Turkey, 2005), especially during times of low sun altitude.

The important conclusion of the present research is the agreement of SD data trends with the global dimming and brightening periods for the years 1970–2010. The decreasing trend between 1970 and the 1990s might be attributed to air pollution, at least partially, at the locations where the measuring systems are installed [11]. We note that more and more cities and towns in Turkey started to use natural gas in heating and in power plants after the 1980s.

Future research topics are to apply such tests to different climatological parameters that are measured for longer time periods. Humidity and precipitation might be some of these parameters to be investigated. Estimations of SSR by models that use more than one measured meteorological parameter (including the bright sunshine hours) may be helpful in combining the information hindered in these long-term datasets. Maybe the most important future prospect is the combination of accumulated satellite data (of about 30 years) with surface-measured climatic data to reach better analysis of recent trends. These studies certainly would make significant contributions to climate change issues, and especially to clarify human-induced climate change.

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