Long-Term Changes in Hot and Cold Extremes in Turkey

Türkiye'nin Sıcak ve Soğuk Ekstremlerindeki Uzun Süreli Değişimler

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ABSTRACT

Extreme weathers are the leading cause of weather-related disasters all over the world. Many people lose their lives each year due to the triggering effect of cold or hot weather. The extreme days are generally defined as a period of several days of abnormally cold or hot weather. Increased frequency of these days could lead to death and disasters.

This study analyzes the variability of minimum and maximum temperature defined anomalous temperature events. Daily minimum and maximum air temperature data from 156 weather stations in Turkey are analyzed to determine percentile threshold values (99th, 95th and 1st, 5th) at each station. Two statistical tests are applied to analyze trend in extreme values, namely Mann-Kendall trend analysis and cluster analysis.

The Mann-.Kendall analysis demonstrates an increase in frequency of hot and extremely hot days, whereas cold and extremely cold days show a decreasing trend in Turkey. The extreme cold days have been the highest of the year 1972, 1983, 1992 and 1993, respectively. After 2005, extreme cold days begin to decrease. The frequency of extreme hot day has increased since 2000. Especially in 2010, it has been the warmest year in Turkey from the records of the stations during the study period.

Keywords: Turkey, Extremes, Cluster Analysis

ÖZ

Ekstrem sıcak havalar, dünyanın her yerindeki hava koşullarına bağlı afetlerin önde başta gelen nedenidir. Soğuk ya da sıcak havanın tetikleyici etkisiyle birçok insan her yıl hayatını kaybetmektedir. Aşırı günler genellikle, anormal derecede soğuk veya sıcak hava koşullarının olduğu birkaç günlük bir süre olarak tanımlanır. Bu günlerin frekansındaki artış, ölüme ve afetlere yol açabilmektedir.

Bu çalışmada minimum ve maksimum sıcaklık verileri için tanımlanan ekstrem sıcaklık olaylarının değişkenliği analiz edilmiştir. Türkiye'deki her bir istasyondaki günlük minimum ve maksimum hava sıcaklığı verileri, her istasyonda persantil eşik değerlerini (99'ncu, 95'nci ve 1'nci, 5'nci) belirlemek için analiz edilmiştir. Ekstrem değerlerdeki değişkenliği analiz etmek için Mann-Kendall trend analizi ve küme analizi olmak üzere iki istatistiksel test uygulanmıştır. Mann-Kendall analizi, sıcak ve aşırı sıcak günlerin sıklığında bir artış olduğunu gösterirken, soğuk ve aşırı soğuk günler Türkiye'de azalan bir eğilim göstermektedir. Ekstrem soğuk günler, sırasıyla 1972, 1983, 1992 ve 1993 yıllarında en fazla yaşanmıştır. 2005'ten sonra ekstrem soğuk günler azalmaya başlamıştır. Ekstrem sıcak günlerin sıklığı 2000 yılından sonra artmıştır. Özellikle 2010 yılı, çalışma periyodu boyunca Türkiye'nin en sıcak yılı olarak kayıtlara geçmiştir.

Anahtar kelimeler: Türkiye, Ekstrem, Küme analizi

1. INTRODUCTION

Many of the effects of climate change are manifested by weather and climate extremes. There is growing interest in quantifying the role of human and other external influences on climate extremes.

Warming of the climate system is unequivocal and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and the sea level has risen (Intergovernmental Panel on Climate Change [Intergovernmental Panel on Climate Change, 2014;).

Temperature and precipitation extremes have been studied at worldwide (Easterling et al., 2000; Frich et al., 2002; Hegerl, Zwiers, Stott, & Kharin, 2004) and regional level (Acar Deniz & Gönençgil, 2015; El Kenawy, Lopez-Moreno, & Vicente-Serrano, 2013; Erlat & Türkeş, 2015; Herting, Seubert, & Jacobeit, 2010; Bindoff et al., 2013). El Kenawy et al. (2013) studied summer temperature extremes in northeastern Spain for 128 stations. They applied Silhouette index for determined the temperature clustering. Their results display that four sub-regions with climatic and geographic meanings are identified: the Mediterranean region, the Cantabrian region and the inland region, the moderately western and southern areas, and the highly elevated areas.

Beniston et al. (2007) suggest that regional surface warming causes the frequency, intensity and duration of heat waves that increases over the European continent. Also, the authors postulate that by the end of the twenty first century, central European countries will especially suffer the same number of hot days as they are currently experiencing in southern Europe. The intensity of extreme temperatures increases in southern Europe more rapidly than in central Europe.

Hertig et al. (2010) suggests that mostly insignificant trends for the 5th percentile of minimum temperatures in winter during the period 1961–1990. They have analyzed significant increases of the 5th percentile of minimum temperatures occurred mainly at stations in the central-northern Mediterranean area with values of more than 2°C in some cases (e.g. Palermo, Italy or Istanbul, Turkey). In addition, the 95th percentile of maximum temperature trend is recorded with mostly in the western Mediterranean area and such trend conversely decreases in the eastern Mediterranean region. Moreover, projections show that heat waves will become more intense, frequent and longer-lasting.

Barbosa, Scotto, and Alonso (2011), have applied quantile regression and clustering to daily mean air temperature over Central Europe. Their results show that most stations exhibit different slopes for the 5%, 50% and 95% quantiles. At the 5% quantile, the largest trends are around 0.15°C decade^{-1}, while at the 95% quantile the largest trends are around 0.20°C decade^{-1}. Their results indicate a tendency towards larger increases in the upper part of the data distribution (large positive temperature anomalies).

Gönençgil, Acar Deniz, and Mestav (2016), suggest that the analysis demonstrated a decrease in frequency of frosty and icy days in Turkey. Especially in 2010, it is the warmest year in Turkey from the records of the stations. In 2010, the fewest frosty days have been recorded during the past 50 years. The very least ice day events have been experienced in 1999, 1984, 2010, 2011, during the past decade.

In this study, Turkey's hot and cold extreme temperature are analyzed by Mann-Kendall trend and cluster analyses. The main goal of this study is to find out if there is a trend in maximum and minimum extremes in Turkey using 156 stations and to cluster the stations to analyze the similarities between them. The structure of this paper is as follows. Section 2 describes data including extreme indices and analysis methods. Section 3 long term variations in extreme temperature and clustering the stations according to indices results. Results are presented in section 4 followed by conclusions in section 5.

2. DATA AND METHODS

Data including daily minimum and maximum temperature is provided by the Turkish State Meteorological Service. There have been 156 stations in the original data since 1966 to 2014. Stations are identified by their number, the station name and their longitude and latitude and elevation information (**Figure 1**). The elevations of the stations are varying between 2m (Anamur and Finike) and 1827m (Ardahan). Turkey is a rough country with a variety of topographical features.

Percentile based indices include occurrence of extreme hot days (99th) and hot days (95th) in summer maximum temperature and occurrence of extreme cold nights (1st) and cold nights (5th) in winter minimum temperature. To present extreme temperature conditions, the 99th, 95th percentile of daily maximum temperatures and the 5th, 1st percentile of daily minimum temperatures are calculated for all station data (**Table 1**).
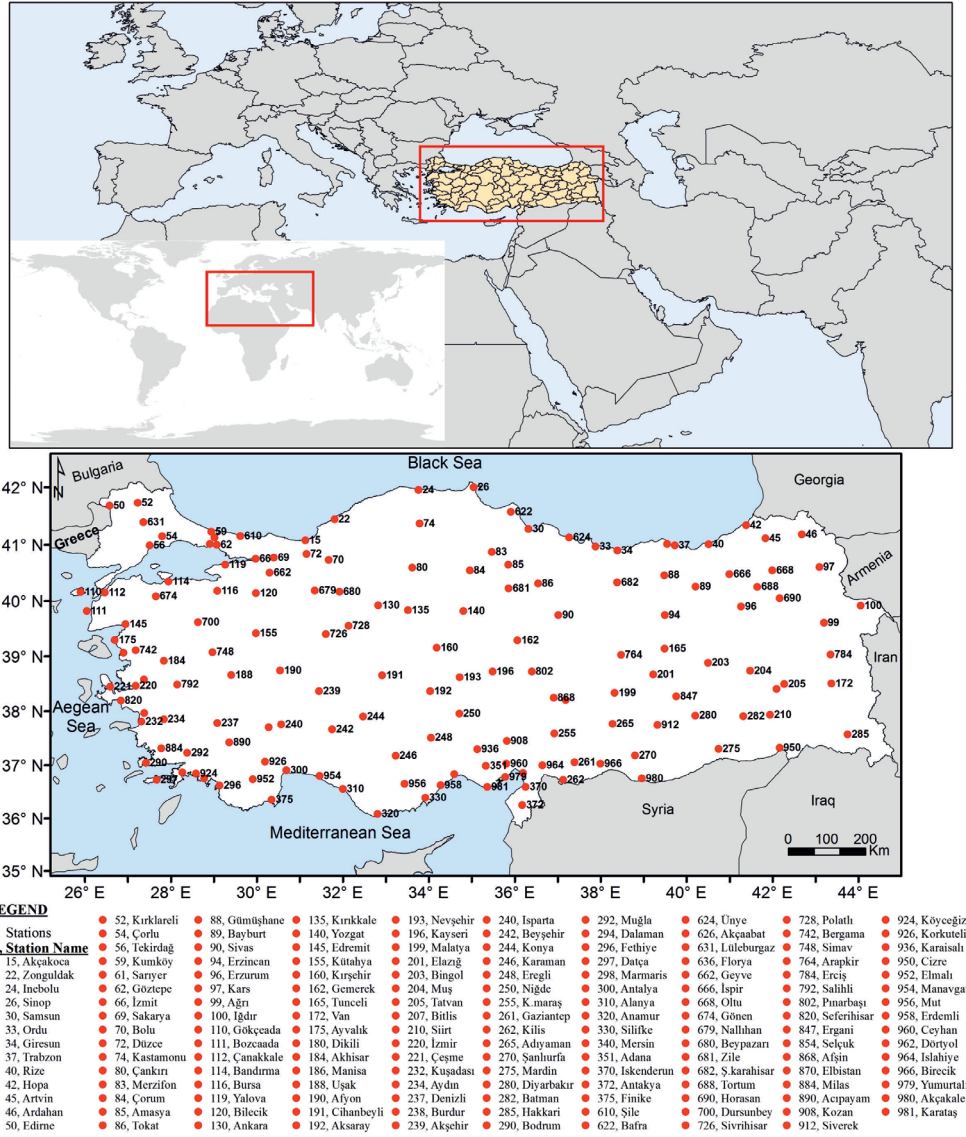
Figure 1: The geographical distribution of meteorological stations.

Table 1: Definitions of the temperature indices used in this study.

Index	Descriptive name	Definition	Units
TX99p	Extremely hot days	Days (or fraction of time) when daily maximum temperature >99th percentile	days (%)
TX95p	Hot days	Days (or fraction of time) when daily minimum temperature >95th percentile	days (%)
TN1p	Extremely cold nights	Days (or fraction of time) when daily minimum temperature <1st percentile	days (%)
TN5p	Cold nights	Days (or fraction of time) when daily minimum temperature <5th percentile	days (%)

According to Herting et al. (2010), the advantage of variable percentiles may be seen in the possibility to use interval-scaled data with a consistent temporal resolution in contrast to the indices resulting from counting the number of events falling below or exceeding a specific reference percentile in a particular season.

Data quality control is performed Kruskal-Wallis test and two statistical tests are carried out in the paper to find out if there is a significant trend in hot and cold extreme values and to cluster the stations. Firstly, the linear trend is computed using the Mann-Kendall's tau statistic at the 95% confidence level. If computed p value is lower than significance level

(p<0.05), the hypothesis can be rejected and it concludes there is a trend in the station where the null hypothesis contains there is no trend where the alternative hypothesis is there is a trend. The Mann-Kendall statistic is a rank-based nonparametric test which is robust to outliers and does not assume normal distribution. According to Mann-Kendall test τ is a value that indicates magnitude of the observations. The *P* statistic is calculated by;

$$P = \sum_{i=1}^{N-1} n_i \qquad (1)$$

Mann Kendall test statistic τ is calculated as follows;

$$\tau = \frac{4P}{N(N-1)} - 1 \qquad (2)$$

The value of the test statistics is normal for all N values, larger than 10. The significance test is calculated as follows;

$$\tau_{(t)} = \frac{(4N + 10)}{9N(N-1)} \qquad (3)$$

where t_g value is the requested probability point in the normal distribution (two sided). A positive value of τ indicates an upward trend while a negative value of τ indicates a downward trend (Kendall, 1975; Mann, 1945). This statistic has been widely used in climatological applications (El Kenawy et al., 2013).

On the other hand, cluster analysis is applied to classify time series data to find out the similarities in the stations. Theoretically, there have been two basic methods for cluster analysis namely, hierarchical and nonhierarchical methods. SPSS has three different procedures that can be used to cluster data: hierarchical cluster analysis, k-means cluster and two-step cluster. If the data set is a mixture of continuous and categorical variables, the two step procedure should be used. If the data set is small and increasing numbers of clusters are allowed, hierarchical clustering can be used. Lastly, if the number of clusters is known and the data set is moderately sized than k-means clustering can be used.

In this analysis, we use hierarchical clustering based on the measure of interval with squared Euclidean distance which is the distance of squared distance on dimension x and y. Squared Euclidean distance is probably the most popular method used in the literature. The distance increases the importance of large distances while weakening the importance of small distance. Squared Euclidean distance can be shown as follows (Ozdamar, 2002):

$$d(i,j) = \sum_{k=1}^{p} (x_{ik} - x_{jk})^2 \qquad (4)$$

where x is the data matrix, i=1,2,…..n; j=1,2,…n and k=1,…,p. n is the sample size, p is the number of variables.

The visual presentation of the distance at which clusters are combined is given by the dendograms. The dendogram is read from left to right, and vertical lines show joined clusters. In the next section, the dendograms and their interpretations are given for each extreme.

3. RESULTS

The analysis of temperature finds out several changes in extreme values during 1966-2014 in Turkey. The results of temperature extremes are defined in this section.

3.1. Extremely Hot and Hot Extremes

Extremely hot and hot extremes display increasing trends at approximately 75-80% stations. An increase in hot days has been observed since after the 1990s. The hot seasons of 2010, 2007, 2000, 2012, 1998, and 2001 have been the most extreme seasons with the highest seasonal maximum temperature.

Figure 2 displays the trends for the 95th percentile of maximum temperatures in summer season. The TX95[th] has increased significantly almost 83% of the stations between 1965 and 2014. Negatively trends that are not statistically significant, appear only 5 stations in TX95[th]. For the hot days, the warming trend is significant at the 1% level for 130 out of 156 stations. Figure 3 displays the temporal distribution of hot and extremely hot days in the period from 1966 to 2014.

Trends for the 99th percentile of maximum temperatures (TX) in summer season are presented in Figure 4. 99th percentile of TX display significant increasing trend (marked with filled triangles) in almost all meteorological stations. Strong warming trends that are mostly significant show spatial coherence over the southwest part of Turkey. Increasing trends are not statistically significant only 20% of stations and these increasing trends are relatively weak.
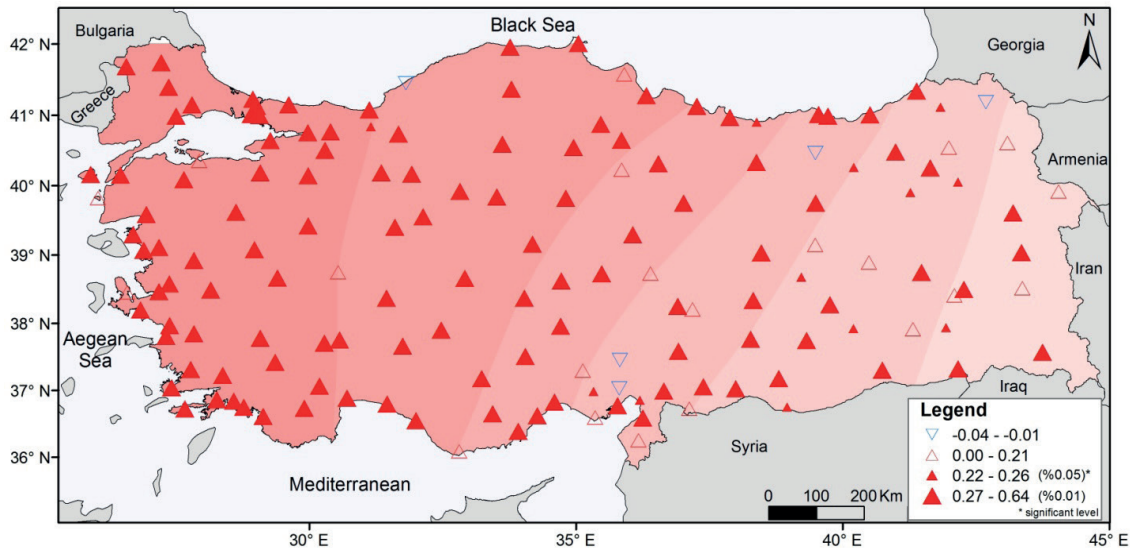
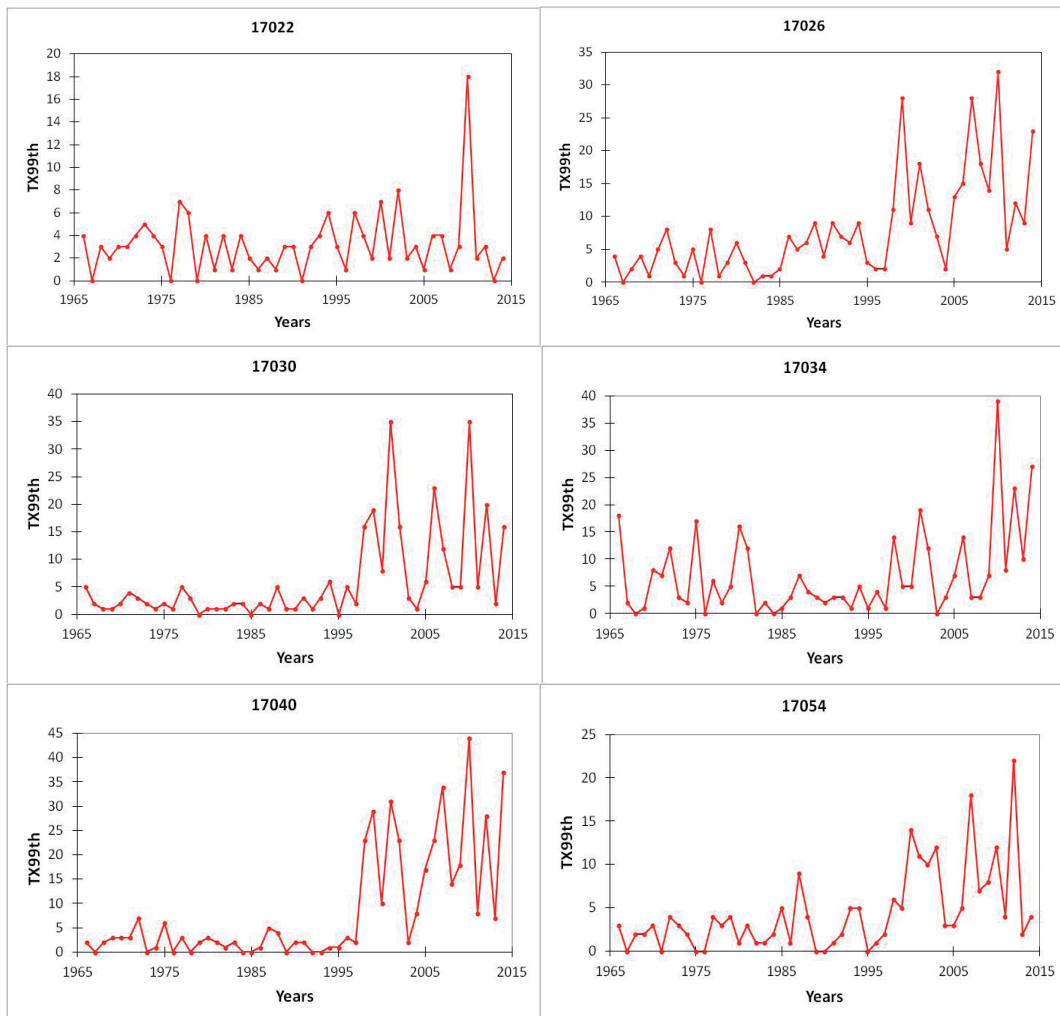**Figure 2:** Trends in daily maximum temperature TX95th index for the period 1966-2014.

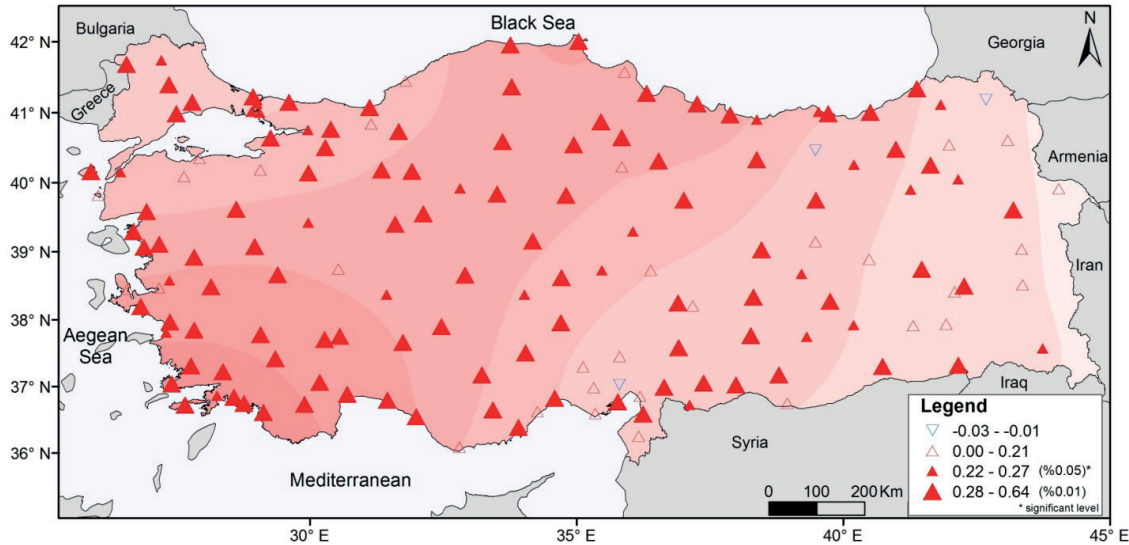**Figure 3:** TX99th temperature indices time series for selected stations over Turkey.

Figure 4: Trends in daily maximum temperature TX99[th] index for the period 1966-2014. Different sizes of triangles indicates different magnitudes of trend.
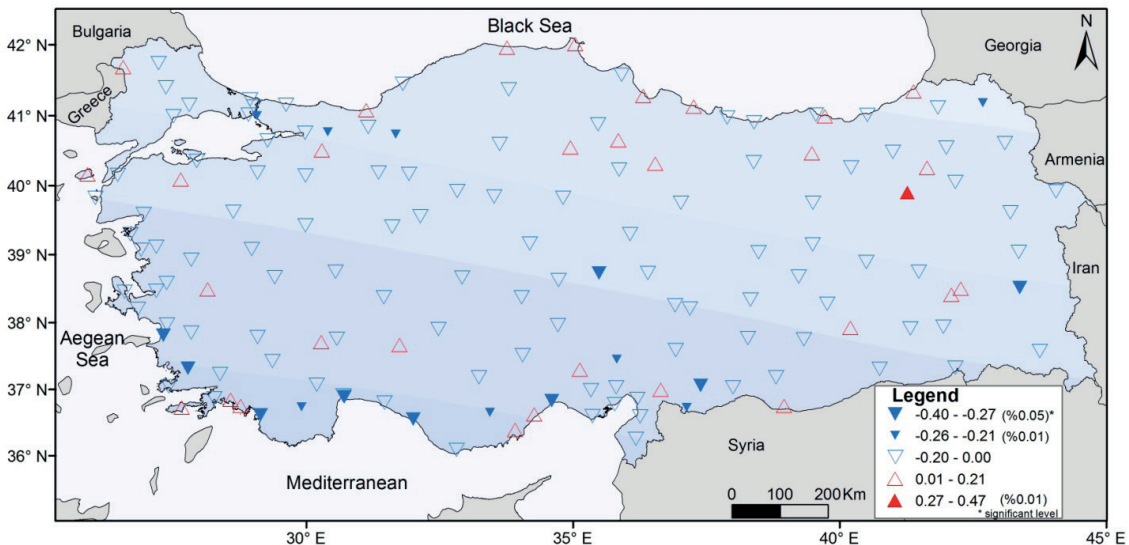

Figure 5: Trends in daily maximum temperature TN5[th] index for the period 1966-2014.

3.2. Extremely Cold and Cold Extremes

Trends for the 5th percentile of minimum temperatures in winter season are presented in Figure 5. A negative trend is seen mostly at stations and this decrease trend indicating a shift in minimum temperature towards warmer conditions for winter season. Especially, the decrease in TN5[th] is statistically significant in the majority of the stations over the Mediterranean Sea coastline.

Figure 6 displays the spatial distribution of the trend for the 1st percentile of maximum temperatures in the winter season. It can be seen as a decreasing trend over most of Turkey, which is statistically significant on the Mediterranean coastline and Marmara Region especially. An increase in trend isobserved in the Black Sea region and the central, southeastern and southwestern parts of Anatolia (only 20 out of 156 stations).

According to Maheras, Xoplaki, and Kutiel (1999), Maheras, Patrikas, Karakostas, and Anagnostopoulou (2000), Xoplaki, Luterbaacter, Burkard, Patrikas, and Maheras (2000) and Feidas et al. (2004), the continuing cooling during the winter is due to an increase in the frequency and persistence of anticyclones over the central Mediterranean and the Balkans.
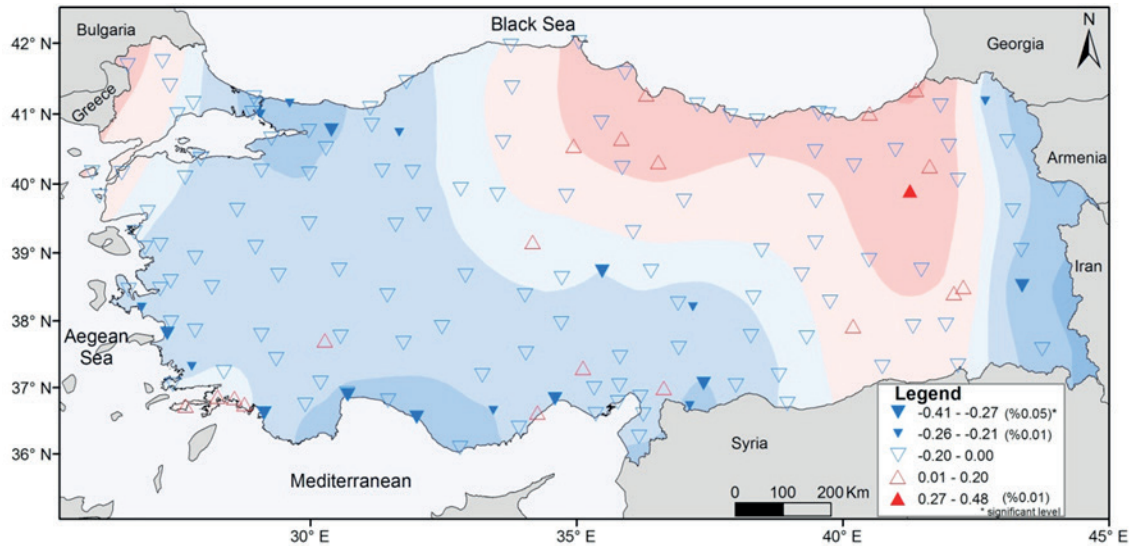
Figure 6: Trends in daily maximum temperature TN1st index for the period 1966-2014.

3.3. Empirical Results

In this section, the empirical results of the analyses outlined in this section are presented. Firstly, the clustering analysis is applied to classify 156 stations to obtain homogeneous groups. The analyses were carried out for temperature extremes for 99th and 95th percentile for maximum summer degrees, 1st and 5th percentile for minimum winter degrees.

First cluster map shows the clusters for 95th percentile for maximum summer degrees. There are 10 clusters, which can generally describe the homogeneous group in 95th maximum temperature. The cluster groups can generally describe the coastal region (West and southern parts of Turkey), the north-

eastern coastal part (only characterized the eastern Black Sea coastal zone), interior (İnland of Turkey) and terrestrial (eastern part of Turkey, the elevation of this area is of average over 1000 m). Cluster 1, 2 and 7 displays the western, southern and northern coastal zones. These areas generally show the maritime effects. Especially, cluster 1 and 2 characterized the Mediterranean climate, which has higher summer temperatures. Cluster 7 characterized cooler part of Turkey in all seasons. This area is similar to oceanic climate with temperature characteristics. Cluster 4 characterized the inland of Turkey, which displays dry interior region. In the summer season, maximum temperatures exceed 30°C. The 95th extreme index has increased in coastal western and southern regions (**Figure 7**). Terrestrial region represented by cluster 8, experienced
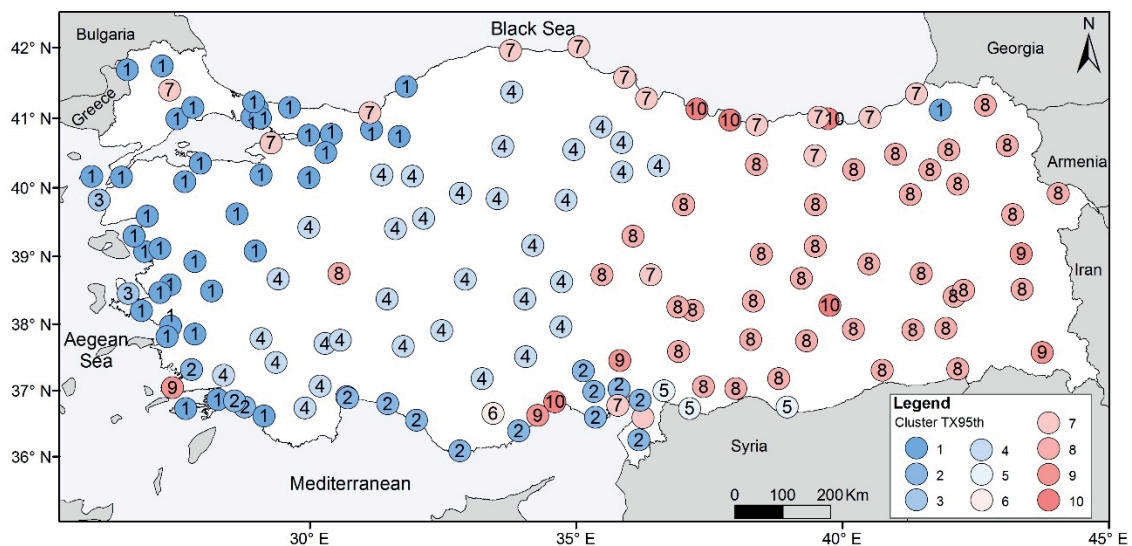

Figure 7: Cluster analysis performed on daily maximum temperature TX95th index.
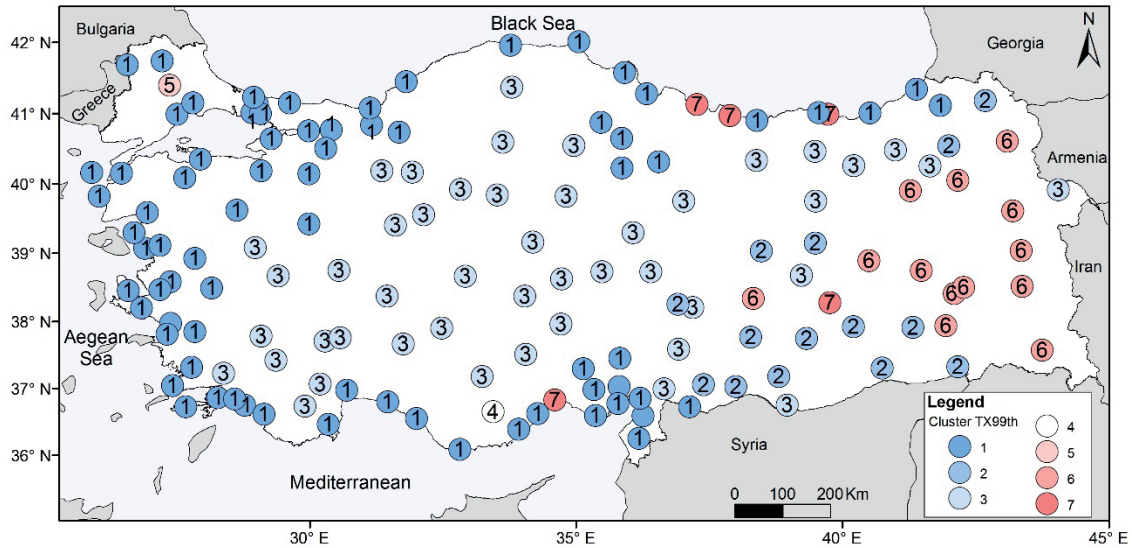
Figure 8: Cluster analysis performed on daily maximum temperature TX99th index.

weakly increases in warm extremes when compared to other regions, especially the western part of Turkey.

The second cluster map shows the clusters for 99th percentile for maximum summer degrees. There are 7 clusters, which generally describe the homogeneous groups in 99th maximum temperature. The cluster groups generally describe coastal regions, transition and terrestrial parts (**Figure 8**). Cluster 1 displays the western, southern and northern coastal zones. The coastal areas are generally affected by the sea. Cluster 3 shows the dry interior region, is to characterize the inner regions of Turkey. In summer season, maximum temperatures are characterized extreme warm days. The 99th extreme index has

increased in coastal western and southern regions (**Figure 3**). The terrestrial regions represented by cluster 6 and 2, experienced weakly increases in the warm extremes when compared to the other regions, especially the western part of Turkey. Transition zone represented by cluster 2, experienced weakly increases which are non-statistically significant. Cluster 2 characterized by highest temperatures experienced during the summer, when the Intertropical Convergence zone (ITCZ) experienced this area due to the northward effect (**Figure 8**).

TN5th (percentage of days per year when the maximum temperature is less than the 5th percentile of the 1966-2014) is displayed in Figure 9. This index shows generally indiscrete 5
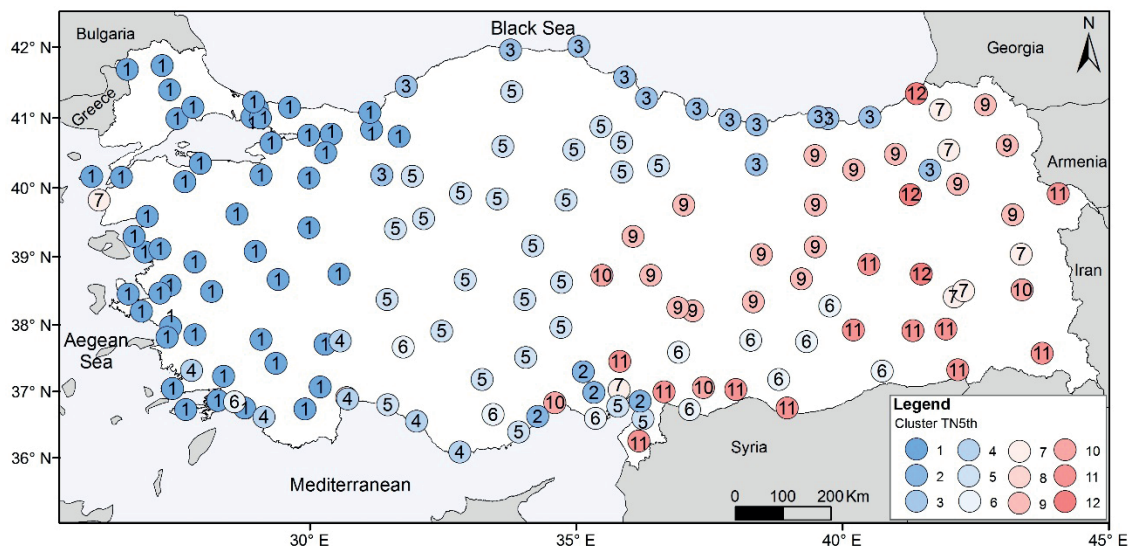

Figure 9: Cluster analysis performed on daily minimum temperature TN5th index.
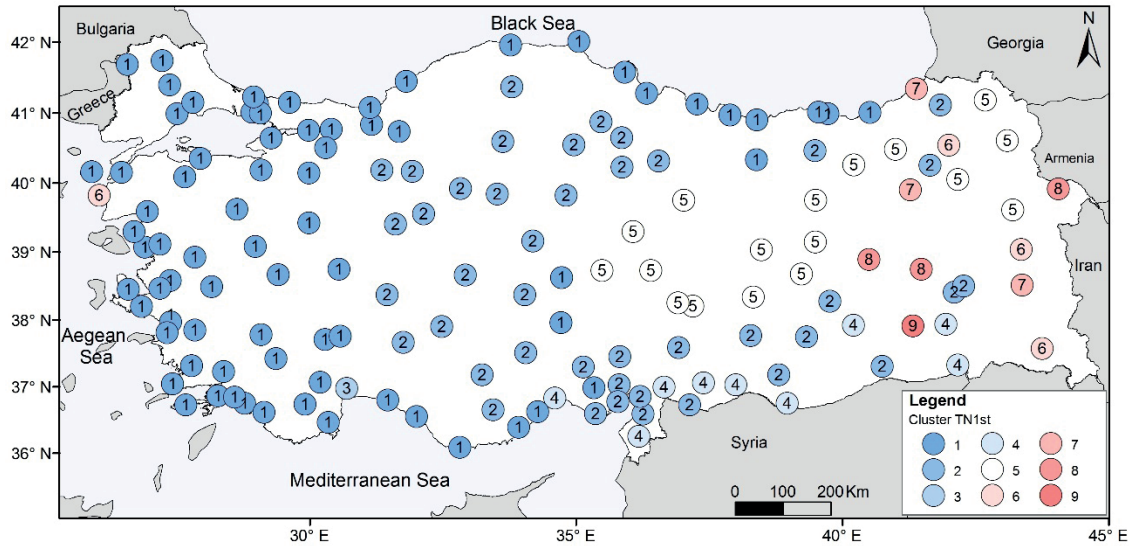
Figure 10: Cluster analysis performed on daily minimum temperature TN1st index.

regions. The cluster groups generally describe coastal, interior, transition and terrestrial parts. Cluster 1 displays the western part of Turkey, which is generally affected by the sea and is influenced by southern air flows in winter. Cluster 5 characterized the inland of Turkey, which is represented by the dry interior region. This region obviously has terrestrial features where the temperatures could drop to below freezing in winter. Terrestrial regions represented by clusters 6, 9 and 11, experienced weakly decreases in the cold extremes. This is the area where the most severe cold extremes have been experienced in Turkey during the winter season.

TN1st index's cluster map shows the 1st percentile for minimum winter temperatures. There are 3 clusters, which generally describe the homogeneous group in 1s minimum temperature. The cluster groups generally describe the coastal (west, southern and northern part of Turkey), interior and terrestrial parts. Cluster 1 shows the western, southern and northern coastal zones. This area is a region where the temperature gradients do not fall very low by maritime effects in the winter season.

Cluster 2 characterized colder parts of Turkey during the winter season. The inland of Turkey represented by cluster 2 shows that the temperature gradients are falling and the number of frosty-icy days are higher in winter compared to the coastal zones. The stations of the terrestrial regions represented by clusters 5, 6, 7 and 8-9. The representation of some of the stations by different clusters is spatially related to the micro-climate features (**Figure 10**).

4. DISCUSSION AND CONCLUSIONS

The threshold values are calculated for each station to determine the temperatures that were above and below the seasonal norms in winter and summer. According to these thresholds, especially summer and winter extremes in recent years, a significant increase in the number of hot days has been observed. According to the Mann-Kendall test, cold days have decreased on the coastlines of the Mediterranean and Marmara Regions (close to Istanbul especially) in winter, as opposed to the hot days which have increased in Turkey during the summer season.

Summer and winter temperatures of Turkey show that the increasing trends in TX99th and TX95th are accompanied with decreasing trends in TN5th and TN1st, indicating a shift in maximum temperature towards warmer conditions for the majority of the stations.

The spatial coherence of the trend patterns is higher for indices of cold extremes TN5th and TN1st than for hot extremes TX99th and TX95th.

During winter, definite changes in cold and extremely cold days are found for the stations over the Mediterranean coastlines and Marmara Region (especially close to Istanbul). In the summer season, pronounced changes in hot and extremely hot days are found all over Turkey.

Hot and extremely hot days have been observed in 2010, 2007, 2000, 2012, 1998 and 2001. Cold and extremely cold

days have been observed in 1992, 1972, 1993, 1983, 1976 and 2008.

Turkey is one of the rapidly urbanizing countries in the developing world. According to the results of the 2007 census, the population of Turkey has increased from 70.586.256 in 2007 to 77.695.904 in 2014 (TUIK, ABPRS 2007-2014). Most of the stations are very likely to have been affected by rapid urbanization, and thus subject to both urban heat island effects in places such as Istanbul, Ankara, Izmir, Bursa, Antalya, Adana etc. In order to objectively group those observatories presenting a similar temporal evolution of summer and winter extremes, the dominant distribution patterns are identified by applying a cluster analysis to the retained factor scores.

Thus, we finally decided to part the clusters in the 7, 10, 9 and 12 groups in TX99[th], TX95[th], TN1[st] and TN5[th], respectively. In general, there are clear climatic and geographic contrasts between the defined regions. The Aegean and Mediterranean coastlines have displayed similar temperature extremes during the winter and summer seasons. The inland regions and the coastlines display clear different characteristics like these inland and elevated areas. In addition to seeing the effects of climate change on hot days and hot nights, urban areas have an important share in this change with the effect of urban heat island. Hot weather conditions or heat waves in Turkey and the region is related to the southern sector of warm air advection, while cold weather in the northern sector is related to the cold air advection. Turkey's classified within the mid-latitudes being open to leads in summer tropical origin air masses and the polar origin air mass in winter. Therefore, the activities of different air masses occur quite often in summer and winter seasons. The results obtained with the study show that the frequency of the hot waves increased after the 2000s and the intensity of the cold waves have decreased since the middle of the 20th century.

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