Turkish Journal of Agricultural and Natural Sciences 12 (2): 342–357, 2025
https://doi.org/10.30910/turkjans.1598495

TÜRK TARIM ve DOĞA BİLİMLERİ DERGİSİ

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TURKISH JOURNAL of AGRICULTURAL and NATURAL SCIENCES

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Original Article

Trend Analysis and Spatial Distribution of Surface Soil Temperatures in Türkiye

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ABSTRACT

Soil temperature is a crucial factor affecting soil's physical, chemical, and biological processes. In particular, the rate of biochemical activities and the soil-plant-water balance are affected by soil temperature. Soil temperature has an important role in many issues such as soil management, water movement in the soil, and planting time determination. Therefore, to know the soil temperature and make predictions about its change in the coming years, the soil temperature trend must also be known. Today, there are many studies on soil temperature. However, studies on the trend of soil temperature are limited, especially in Türkiye. In this study, soil temperature trends over the period between 1981 and 2021 were analyzed on a monthly scale at 5 and 20 cm depths using 73 meteorological stations in Türkiye. Also, the relationships between air and soil temperature were examined during the same period. The results yielded a high correlation between air and soil temperature. According to the monthly trend analysis of soil temperature, there was a predominance of positive trends at both soil depths. For 5 cm and 20 cm-depths, the distribution of significant positive trends was the highest in March (78.08% and 83.56%, respectively), while significant negative trend distribution was the highest in June (9.59%) and July (4.11%), respectively. Increasing soil temperatures will affect many soil characteristics and agricultural production processes. It should be noted that the increase in soil temperature may positively affect plant germination and root development, but soil moisture balance and biochemical negatively affect soil properties. Planning sustainable soil management practices, including soil tillage, to reduce the increase in soil temperatures has become necessary. Therefore, activities that may cause an increase in soil temperature should be controlled and monitored.

Key words: Soil Temperature, Trend Analysis, Mann-Kendall, Soil management, Türkiye

Türkiye’de Yüzey Toprak Sıcaklıklarının Trend Analizi ve Mekansâl Dağılımı

ÖZ

Toprak sıcaklığı, topraktaki fiziksel, kimyasal ve biyolojik olaylara etki eden önemli bir faktördür. Özellikle biyokimyasal aktivitelerin hızı ve toprak-bitki-su dengesi toprak sıcaklığının etkisi altındadır. Ancak günümüzde toprak sıcaklığı hakkında yapılan çalışmalar oldukça sınırlıdır. Toprak sıcaklığı ve bu sıcaklığın zamana bağlı olan değişimleri hakkında yeterli bilgiye sahip olmak ekosistem ve tarımsal üretim için oldukça önemlidir. Bu çalışmada, Türkiye'deki 73 iklim istasyonu kullanılarak 1981 ile 2021 yılları arasındaki dönemde toprak sıcaklığı eğilimleri aylık ölçekte 5 ve 20 cm derinliklerde analiz edilmiştir. Bununla birlikte aynı döneme ait hava ve toprak sıcaklığı arasındaki ilişkiler belirlenmeye çalışılmıştır. Araştırma sonuçları hava ve toprak sıcaklığı arasında yüksek korelasyonun olduğunu göstermiştir. Toprak sıcaklığının aylık eğilim analizleri sonuçlarına göre her iki toprak derinliğinde pozitif trendlerin fazla olduğu belirlenmiştir. 5 cm ve 20 cm derinlikler için, önemli pozitif trend dağılımı en fazla Mart (sırasıyla %78.08 ve %83.56) ayında önemli negatif trend dağılımı ise sırasıyla en fazla Haziran (% 9.59) ve Temmuz (% 4.11) aylarında belirlenmiştir. Artan toprak sıcaklıkları toprakların birçok özelliğini etkilediği gibi tarımsal üretim süreçlerini de etkilemesi muhtemeldir. Toprak sıcaklıklarının artışını azaltacak başta toprak işleme gibi sürdürülebilir toprak yönetim uygulamalarının planlanması bir zorunluluk haline gelmiştir. Bundan dolayı toprak sıcaklığının artışına neden olabilecek faaliyetler kontrol altına alınarak izlenilmelidir.

Anahtar kelimeler: Toprak Sıcaklığı, Trend analizi, Mann-Kendall, Toprak yönetimi, Türkiye

INTRODUCTION

Soil temperature is a crucial soil property that directly or indirectly affects several physical, chemical, and biological processes within the soil. Soil temperature is an important ecological factor that affects plant life at all stages, from seed germination to seedling growth and development. As with air temperature, soil temperature is vital for plant growth. Soil temperature is necessary to calculate underground ecosystem processes, including root growth and respiration (Repo et al., 2004), decomposition, and nitrogen mineralization (Waring & Running, 2007; Onwuka & Mang, 2018). Furthermore, soil temperature is critical for physical, hydrological and biogeochemical processes (He et al., 2018). Soil temperature could be a significant factor in retaining soil organic carbon as it can affect biomass production and microbial decomposition of organic matter (Chowdhury et al., 2021). Soil temperature varies along the soil profile depending on factors including soil structure, meteorological conditions, vegetation cover, etc. (Ekberli et al., 2017). Temperature changes with time and depth within the soil profile. The temperature at the soil surface significantly fluctuates during certain hours of the day. However, daily variations in deeper parts of the profile (typically at a depth of 50 cm) are negligible. Seasonal temperature changes can affect deeper layers. Yener et al, (2017) reported that soil and air temperatures showed the same trend over time. However, short-term meteorological effects such as rain, snow and wind increased the percentage of error rates at shallow depths. In most soils, the temperature remains relatively constant at a depth of 10 m, approximately equaling the annual average temperature of the upper soil layer (Dinç & Şenol, 1998). The majority of soil formation processes and events occur within specific temperature ranges. Increasing or decreasing temperatures can adversely affect many of the processes mentioned above (Onwuka & Mang, 2018).

The primary source of soil heat is solar energy coming to the Earth's surface with rays from the sun. Solar rays reaching the Earth show their effect on the soil depending on its physical and chemical properties (color, water content, structure), topography, and vegetation status (Ergene, 2012). Soil temperature exhibits daily, monthly, and seasonal variations depending on the temperature in the atmosphere. Therefore, global temperature increases and decreases in the atmosphere directly affect soil temperature. Despite the importance of soil temperature, the majority of studies conducted worldwide today have focused on temperature and precipitation trends (Jain & Kumar, 2012; Saboohi et al., 2012; Caloiero, 2015; Doğan Demir & Demir, 2016; Doğan Demir et al., 2017; Yildirim & Rahman, 2022; Demir & Doğan Demir, 2023). Studies on the temporal trend of soil temperature are relatively limited. According to research, in the first two decades of the 21st century (2001–2020), global surface temperature was found to be 0.99 [0.84 to 1.10] °C higher than in 1850–1900 (Masson-Delmotte et al., 2021). Several studies conducted on a local basis showed a positive or negative trend in soil temperature, which needs to be evaluated in terms of agricultural production (Araghi et al., 2017; Fang et al., 2019; Dorau et al., 2022). The majority of research in Türkiye has focused on temperature and precipitation trends, and studies on the trend of soil temperature across the country are limited. The studies conducted in this regard are generally at the local level. Kara and Cemek (2019) tried to estimate soil temperature using meteorological parameters of some provinces in the north of Türkiye with artificial neural networks. Ekberli et al (2017) reported in their studies that the daily change of soil temperature at different depths could be estimated using thermal diffusion coefficients determined by parabolic function. Güleryüz (2022) reported in his study that soil temperature at different depths can be estimated using machine learning algorithm. Yeşilırmak (2013) calculated the trend analysis of soil temperatures to varying depths in 8 meteorological stations in the west of Türkiye. As a result of the research, it was determined that there was an increasing trend at all depths of the soil. It was reported that long-term trend analyses could provide important information about meteorological change. Similarly, Tonkaz et al. (2007) investigated temporal trends in soil temperatures between 1975 and 2004 for 13 sites in the Southeastern of Türkiye. They found that soil temperatures showed significant increasing trends. However, soil temperature trends in other regions of Türkiye have never been analysed.

The present study aimed to use soil temperature values (5 cm and 20 cm) from 1980 to 2021 from meteorological stations at 73 points across Türkiye to (i) conduct trend analysis, (ii) map the results of trend analysis, and (iii) evaluate the results in terms of some soil properties.

MATERIALS AND METHODS

Study Area

The present study was carried out to cover all of Türkiye. Türkiye is located in the middle belt of the northern hemisphere, where the terrestrial zone of Türkiye occupies a large area between the latitudes 36-42 degrees north and meridians 26-45 degrees east. Due to its rugged geography, its projected area is 779,452 km², while its actual area is 814,578 km² (Atalay, 2011). The country's average elevation is 1142 m with an average slope of 17% (Elibüyük and Yılmaz, 2010). Türkiye lies between the temperate and subtropical zones. The fact that seas surround three sides of Türkiye, the extension of the mountains, and the diversity of landforms have led to different climate types (such as continental, Mediterranean, and Black Sea climates). In 2021, the average temperature in Türkiye was 1.4°C higher than the 1981–2010 average of 13.5°C, with a mean temperature of 14.9°C. The total spatial precipitation in Türkiye in 2021 was 524.8 mm, 9% below the 1991-2020 normal (573.4 mm) (MGM, 2022). In this study, meteorological stations in 73 provinces of Türkiye were selected as the study area (Fig. 1).

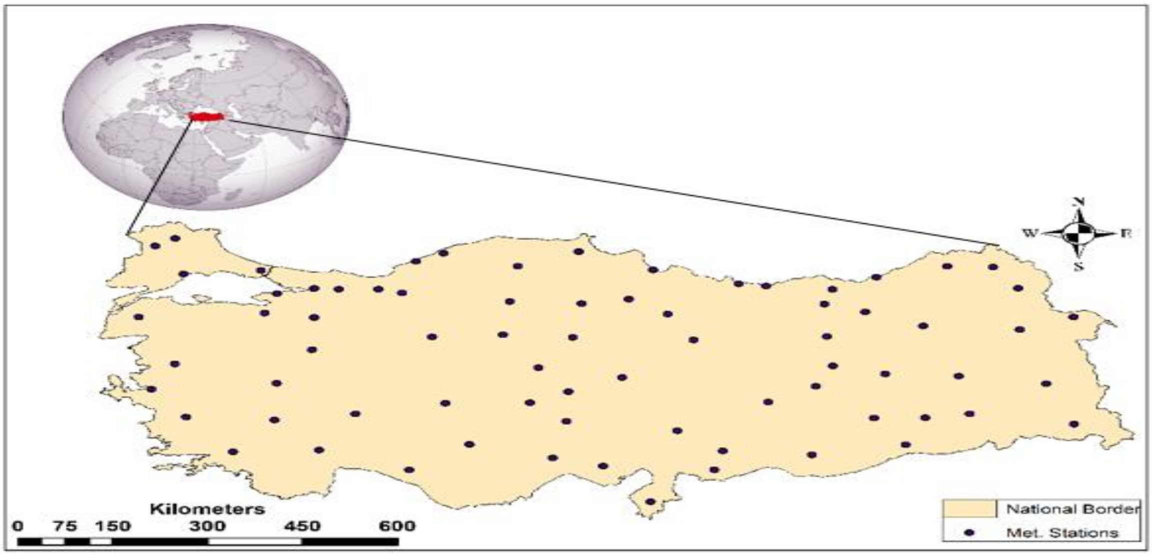

Figure 1. Study area and locations of meteorological stations

Data collection

The data used in the study was obtained from the Turkish State Meteorological Service (MGM). Meteorological stations (MS) in 73 provinces across Türkiye, which have regular and complete measurement records between 1980 and 2021, provided soil temperature (ST) measurement values. At the MS, soil temperature at different depths is measured using specialized thermometers and automatically recorded by thermographs. The standard depths for soil temperature measurement are 5, 10, 20, 50, and 100 cm. However, in this study, temperatures in the upper soil layer (0-20 cm), where the physical, chemical, and biological properties of the soil are most dynamic, were evaluated. For this purpose, monthly average soil temperature values at depths of 5 cm and 20 cm were analyzed across 73 MS from 1980 to 2021.

Trend analysis

The Mann-Kendall test has been preferred due to its widespread use in determining the possible trend in monthly average temperature series at two different depths of the surface soil. However, the non-parametric nature of the Mann-Kendall test, which can work for all distributions, has led to its preference in this study (Khambhammettu, 2005). The Mann-Kendall statistical test for trend is used to evaluate whether a series of data values increase or decrease over time and whether the trend in both directions is statistically significant (Gillbert, 1987). This method ranks among the most preferred and reliable methods for determining trends in climatological and hydrological data (Burn et al. 2002). With this test, the presence of a trend in a time series is checked with the "H0: no trend" (null hypothesis). Accordingly, the test statistic S and the sign function, as given in Equations 1 and 2, are calculated. Then, the variance of S and the Z test statistic is determined using the formulas given in Equations 3 and 4, respectively.

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

$$sgn(x_j - x_k) = \begin{cases} 1; xj > xi \\ 0; xj = xj \\ -1; xj < xj \end{cases} \quad (2)$$

$$VAR(S) = \frac{1}{18}[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)] \quad (3)$$

Then the test statistic Z is denoted by Eq.(4)

$$Z_s = \begin{cases} \frac{S-1}{\sqrt{var(S)}}, if\ S > 0 \\ 0, if\ S = 0 \\ \frac{S+1}{\sqrt{var(S)}}, if\ S < 0 \end{cases} \quad (4)$$

Here, n represents the number of data, x represents the data at times i and j, m represents the number of observations repeated in the data set, and ti represents the repeated observations in a series of length i. The Z value is used to determine a statistically significant trend. If |Z| < α / 2 at the significance level α, there is no significant trend, whereas if |Z| ≥ α / 2, there is a statistically significant trend, and depending on the sign of the S value, it is concluded whether the trend is increasing or decreasing. In this study, the Zα/2 value at a 95% confidence interval is taken as ±1.96 according to normal distribution tables. The trend for each MS is classified as shown in Table 1 in the analysis results.

Table 1. Coding trend statistical test results according to significance level

Trend Test (Zs)	Trend Code	Explanation
Zs <-1.96	1	Significant Negative Trend (SNT)
0 < Zs <-1.96	2	Insignificant Negative Trend (INT)
Zs=0	3	No Trend (NT)
0 < Zs <1.96	4	Insignificant Positive Trend (IPT)
Zs >1.96	5	Significant Positive Trend (SPT)

Spatial Distribution of Trend Analysis Results

Since it is impossible to measure temperature at every point in Türkiye due to its different topographic structure, it is essential to determine soil temperatures and temperature trends by estimating them. Thus, data for areas without meteorological stations can be calculated. In our study, trend values of each meteorological station (MS) were mapped using Geographic Information Systems (GIS). For this purpose, trend values calculated for 5 cm and 20 cm depths in 73 MS were processed into ArcMAP and monthly distribution maps were produced using the Inverse distance weighting (IDW) method. The IDW interpolation method assumes that data sets close to each other are more similar than those farther away (Hodam et al., 2017; Isaaks & Srivastava, 1989). The method uses the values of surrounding measurements to estimate the value of an unscaled datum. The IDW method assumes that each measured point has a diminishing positional effect with distance. It gives higher weights to nearby points than distant ones (Hodam et al., 2017).

General equation in IDW;

$$\hat{Z}(S_o) = \sum_{i=0}^{n} \lambda_i Z(S_i) \quad (5)$$

Where $\hat{Z}(S_o)$ is the value, we are trying to predict for location So; n is the number of measured sample points surrounding the prediction location that will be used in the prediction; λ_i are the weight assigned to each measured points that we are going to use. These weights will decrease with distance. $Z(S_i)$ is the observed value at the location S_i.

The weights at location S_i can be determined by;

$$\lambda_i = \frac{d_{i0}^{-p}}{\sum_{i=1}^{N} d_{i0}^{-p} \sum_{i=1}^{N} \lambda_i} = 1 \quad (6)$$

As the distance becomes larger, the weight is reduced by a factor of p. The quantity d_i_0 is the distance between the prediction location, s_0 and each of the measured locations, S_i. The power parameter p influences the weighting of the measured location value on the prediction location's value; that is, with the increase of distance between the measured sample locations, and the prediction location, the weight (or influence) that the measured point will have on the prediction will decrease exponentially. The weights for the measured location that will be used for the prediction are so scaled that their sum equals 5 (Hodam et al., 2017).

Table 2. Descriptive statistical data on soil (5 and 20 cm) and air temperature values measured at 73 meteorological stations in Türkiye between 1980-2021

Months	Min	Max	Med	Mean	SD	VC	Skewness	Kurtosis	SE of Mean	Lower bound on mean (95%)	Upper bound on mean (95%)
Air Temperature (°C)											
Jan	-18.20	13.10	2.90	2.10	5.32	2.54	-0.82	0.64	0.10	1.90	2.29
Feb	-17.00	14.80	4.00	3.20	5.12	1.60	-0.86	0.79	0.09	3.02	3.39
Mar	-13.40	17.70	7.40	6.93	4.16	0.60	-0.76	1.38	0.08	6.78	7.08
Apr	-0.80	21.70	11.80	11.91	3.22	0.27	-0.12	0.20	0.06	11.79	12.02
May	6.60	25.10	16.40	16.57	3.07	0.19	-0.09	0.04	0.06	16.46	16.69
Jun	11.10	30.80	21.00	21.17	3.31	0.16	-0.05	-0.12	0.06	21.05	21.29
Jul	13.80	34.80	24.20	24.40	3.50	0.14	0.09	-0.20	0.06	24.27	24.53
Aug	13.30	34.00	24.20	24.40	3.45	0.14	-0.02	-0.27	0.06	24.27	24.52
Sep	9.60	30.90	20.20	20.40	3.46	0.17	0.07	-0.16	0.06	20.27	20.52
Oct	3.70	26.00	14.80	14.89	3.57	0.24	0.02	-0.07	0.07	14.76	15.02
Nov	-6.00	20.10	8.60	8.61	4.07	0.47	-0.24	-0.01	0.08	8.47	8.76
Dec	-17.80	14.80	4.60	4.18	4.92	1.18	-0.66	0.58	0.09	4.00	4.35
Soil Temperature (5cm)											
Jan	-20.10	11.80	3.10	2.78	3.79	1.36	-0.57	0.93	0.07	2.64	2.92
Feb	-20.50	13.30	4.40	3.97	3.90	0.98	-0.61	1.00	0.07	3.83	4.11
Mar	-12.20	18.60	8.40	8.13	3.66	0.45	-0.48	1.09	0.07	7.99	8.26
Apr	1.40	25.20	14.00	14.11	3.30	0.23	-0.10	0.56	0.06	13.99	14.23
May	5.10	31.00	20.00	20.08	3.36	0.17	-0.12	0.41	0.06	19.96	20.20
Jun	8.40	39.50	25.50	25.71	3.79	0.15	-0.08	0.42	0.07	25.57	25.84
Jul	13.40	40.40	29.30	29.59	4.10	0.14	0.02	-0.11	0.08	29.44	29.73
Aug	11.90	39.50	29.10	29.37	4.04	0.14	-0.06	-0.15	0.07	29.22	29.52
Sep	9.70	36.10	23.70	24.17	3.87	0.16	0.12	-0.07	0.07	24.03	24.31
Oct	4.50	31.90	16.40	16.54	3.68	0.22	0.17	0.27	0.07	16.41	16.68
Nov	-3.90	22.40	8.90	8.87	3.57	0.40	-0.07	-0.21	0.07	8.74	9.00
Dec	-9.70	13.70	4.50	4.47	3.67	0.82	-0.29	-0.07	0.07	4.33	4.60
Soil Temperature (20 cm)											
Jan	-10.20	12.20	3.90	3.98	3.03	0.76	-0.04	0.23	0.06	3.87	4.09
Feb	-12.10	13.50	4.70	4.57	3.28	0.72	-0.15	0.23	0.06	4.45	4.69
Mar	-9.40	18.30	8.10	7.89	3.45	0.44	-0.26	0.47	0.06	7.76	8.01
Apr	0.40	24.10	13.20	13.21	3.26	0.25	-0.26	0.79	0.06	13.09	13.32
May	4.30	28.60	18.70	18.70	3.25	0.17	-0.19	0.44	0.06	18.58	18.82
Jun	8.40	33.50	23.80	23.89	3.48	0.15	-0.26	0.51	0.06	23.76	24.01
Jul	13.50	37.80	27.30	27.48	3.59	0.13	-0.16	0.12	0.07	27.35	27.61
Aug	15.70	37.70	27.60	27.73	3.59	0.13	-0.17	0.04	0.07	27.60	27.86
Sep	12.40	35.10	23.50	23.80	3.53	0.15	0.05	0.01	0.07	23.68	23.93
Oct	5.40	33.30	17.10	17.30	3.51	0.20	0.17	0.30	0.06	17.17	17.43
Nov	-1.20	20.20	10.20	10.13	3.39	0.33	0.00	-0.34	0.06	10.01	10.26
Dec	-6.80	14.20	5.70	5.74	3.24	0.56	0.01	-0.51	0.06	5.62	5.86

SD: standard deviation, Med: Median, CV: coefficient of variation, SE: standart error

RESULTS AND DISCUSSION

The descriptive statistical values of air and soil temperatures (at depths of 5 cm and 20 cm) measured between 1980 and 2021 in Türkiye are provided in Table 2. The lowest temperature recorded in Türkiye was -18.2°C in January 2008 at the Ardahan station, while the highest temperature was 34.80°C in July 2000 at the Şanlıurfa station. Similarly, the average lowest and highest temperatures were recorded in January and July-August, respectively. The lowest temperature at a depth of 5 cm was -20.5°C in February 1991 at the Ardahan station, and the highest temperature was 40.40°C in July 2012 at the Aydın station. The average lowest and highest temperatures at the same depth occurred in January (2.78°C) and July (29.59°C), respectively. Likewise, the lowest temperature measured at a depth of 20 cm was in February 1991 at Ardahan station, while the highest temperature was 37.8°C in July 2016 at the Mersin station. The average lowest and highest temperatures at this depth occurred in January (3.98°C) and August (27.73°C), respectively. Consequently, the lowest temperatures measured between 1980 and 2021 were observed at the Ardahan station for air and soil temperatures. However, high-temperature data were recorded at different stations, with all high temperatures occurring within the last 10 yearsThe fluctuation in air temperatures has been observed to cause variations in soil temperature. The present study presents the relationships between air and soil temperatures measured at the same stations in Figures 2. Based on data obtained from 73 meterological stations evaluated within the scope of the present study, the effect of air temperatures on soil temperature at a depth of 5 cm in Türkiye is most pronounced in March (r^2=0.975). The most minor effect was determined in June and July (r^2=0.880). Similarly, the effect of air temperatures on soil temperature at a depth of 20 cm is highest again in March (r^2=0.955) and lowest in January (r^2=0.880). Soil temperature is affected by several soil properties. Dark-colored soils absorb heat more effectively, resulting in more substantial warming. Additionally, increased organic matter content enhances water retention capacity and color intensity, leading to an increase in soil temperature (Ochsner et al., 2001; Fang et al., 2005). However, these soil characteristics can either amplify or diminish the effect of heat reaching the soil.

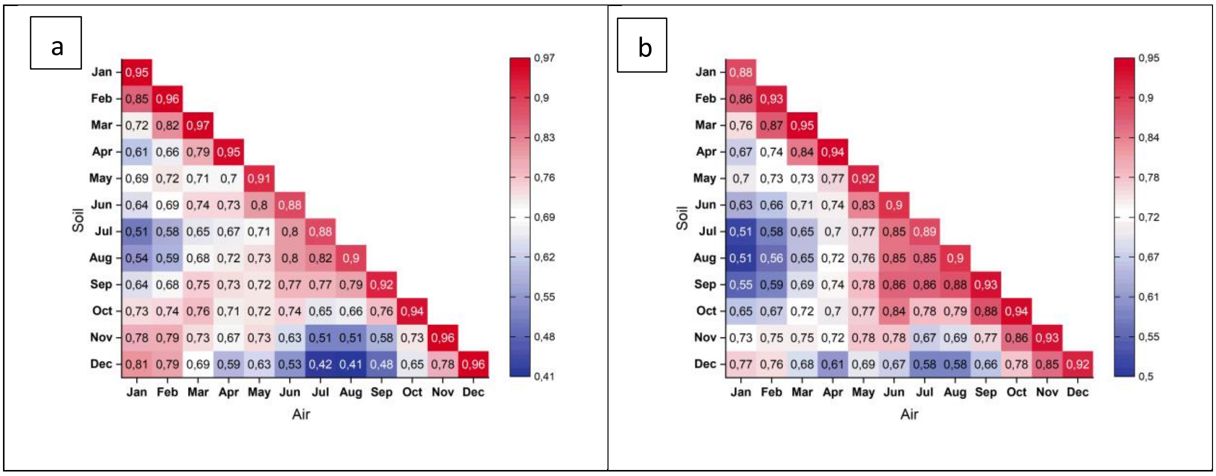

Figure 2. Correlation analysis of monthly averages of soil and air temperature measured at 73 meteorological stations in Türkiye between 1980-2021 - a: Correlation between soil temperature at a depth of 5 cm and air temperature, b: Correlation between soil temperature at a depth of 20 cm and air temperature

A high correlation was detected between the air temperature and soil temperature in Türkiye, depending on these interactions. Generally, the temperature change on the soil surface is more substantial than the changes occurring in the deeper layers. Depending on the increase or decrease of temperature waves reaching the soil, a process occurs in which temperature waves are delayed and attenuated in the deeper layers of the soil due to the retention or release of a certain amount of heat. The delay time of the maximum (minimum) temperature at any given time on the soil surface along the soil profile is a function of soil depth, thermal diffusivity, and the frequency of temperature waves. The delay time is directly proportional to the soil depth and inversely proportional to thermal diffusivity and the frequency of temperature waves (Hillel, 1998; Gülser and Ekberli, 2004). In our study, although high correlations were obtained between the air temperature averages and the soil temperature averages measured simultaneously, soil temperature is under the influence of solar energy and the physical and chemical properties of the soil (Kantarcı, 2000). However, air temperature is still the most important parameter that can be used in estimating soil temperature. Many researchers on this subject have concluded that air and soil temperatures follow each other (Chudinova et al., 2006; Jahromi et al., 2021). However, Bolat (2023) reported that there is a linear positive relationship between air temperature and soil temperature. In Figure 2, it is noted that the correlation coefficients in the graph are low in June, July and August when the air temperature is high and high in other months. In these months, soil moisture is lower than in other months in Türkiye's climate conditions. A similar relationship is not seen when the correlation results in the b graph in Figure 2 are examined.

Trends of soil temperature

Remarkable results were obtained in the present study conducted using soil temperature values from 73 meteorological stations across Türkiye. Trend analyses revealed both positive and negative changes. The trend analysis results based on soil temperature values at a depth of 5 cm and 20 cm are presented monthly in Fig. 3.

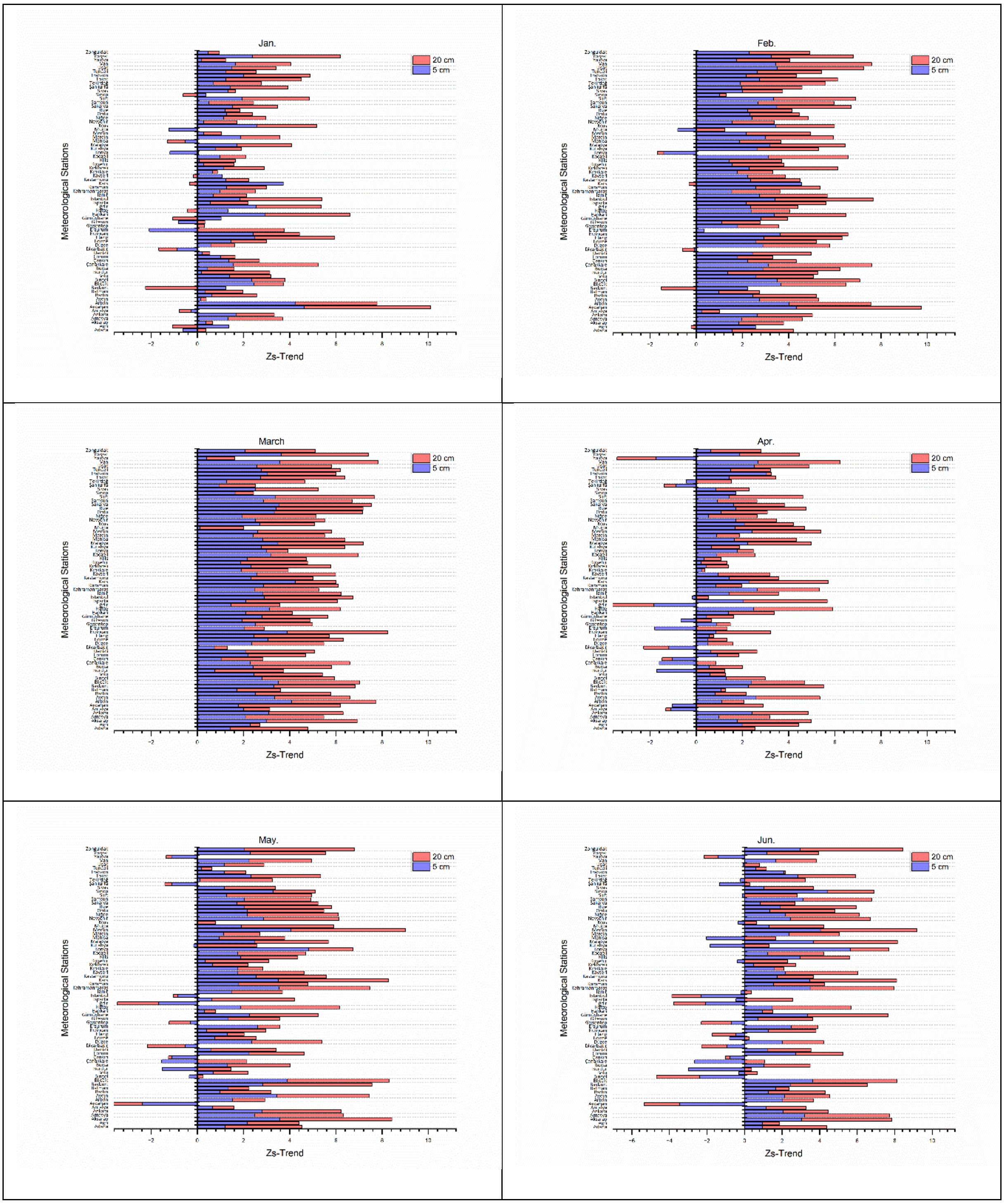

Figure 3. Trend analysis values of soil temperatures at 5 and 20 cm depths measured at 73 meteorological stations in Türkiye between 1980-2021

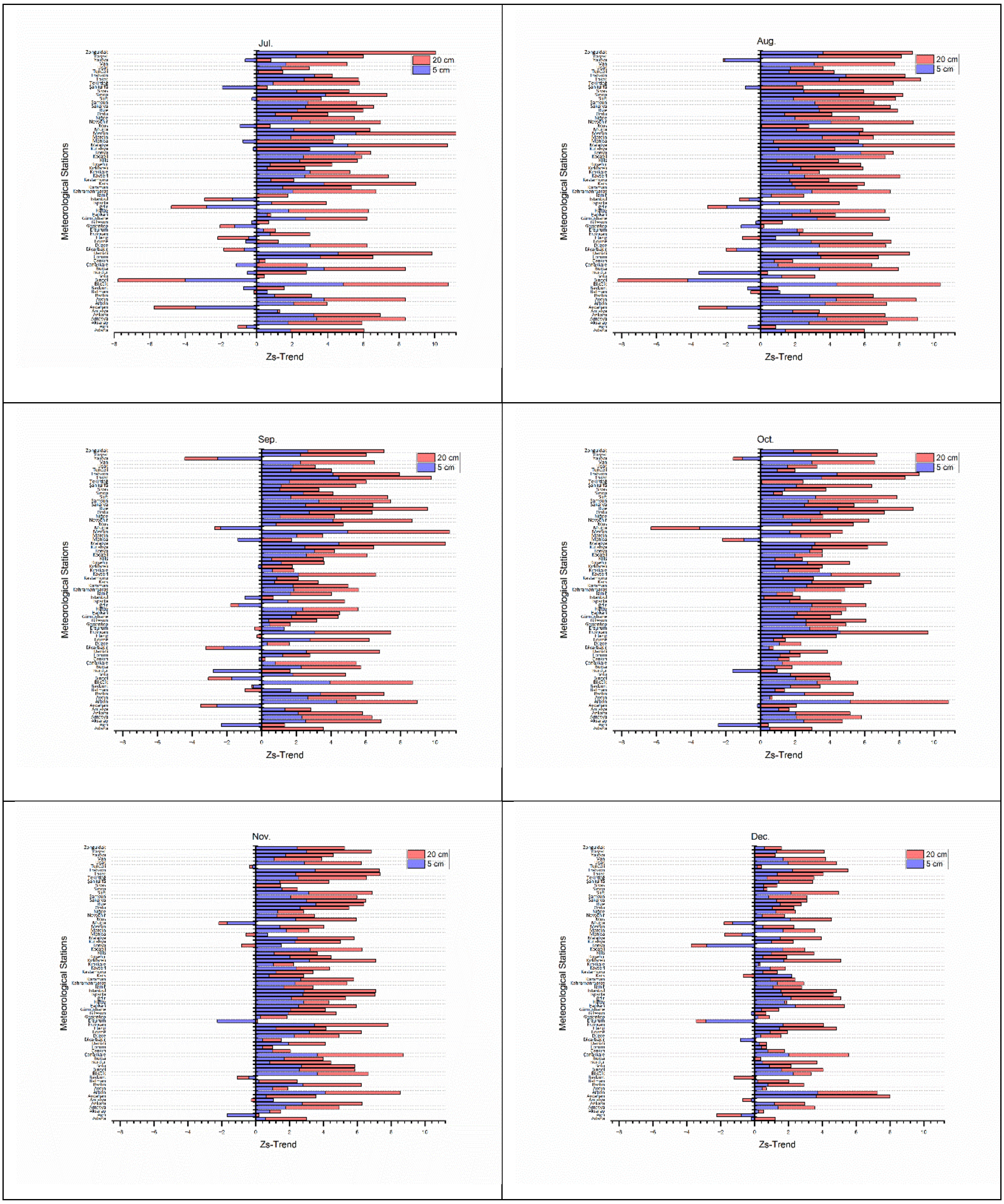

Figure 3. (Contiuned)

In our study, monthly spatial distribution maps of soil temperature trend values were obtained according to the IDW method using the trend data of 73 meteorological stations given in Figure 3 (Fig 4). Thus, the trend values of the areas between known points were calculated according to the IDW method.

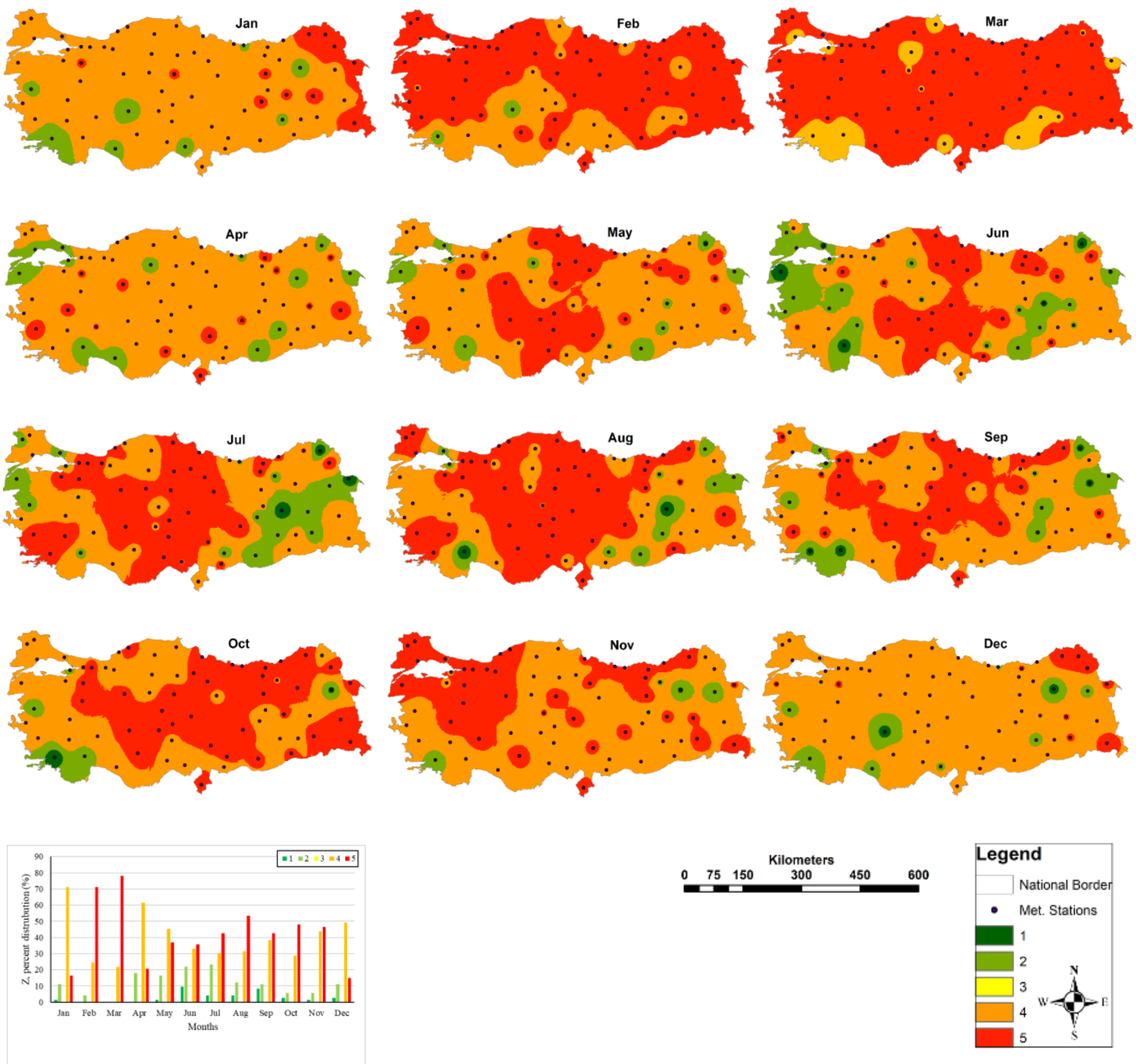

Figure 4. Distribution of trend analysis results of soil temperature at 5 cm depth measured monthly at 73 meteorological stations in Türkiye between 1980-2021 according to the IDW method (1: Significant decreasing trend, 2: Decreasing trend, 3: No trend, 4: Increasing trend, 5: Significant increasing trend)

As observed from the figure, the highest positive trend in soil temperature in Türkiye was determined in March. In March, a Significant Positive Trend (SPT) was identified in 78.08% of the stations where soil temperature measurements were taken. In February, the distribution of the increasing trend in soil temperature in Türkiye was determined to be 71.23% SPT. According to the analysis results, the distribution of the increasing trend in soil temperature in January, December, and April was found to be an Insignificant Positive Trend (IPT). Conversely, the lowest negative trend distribution was observed in July. In July, Significant Negative Trend (SNT) was detected in 9.59% of the stations where soil temperature measurements were taken. According to the trend analysis results, areas where an increase in soil temperature occurred at a depth of 5 cm in Türkiye were noticeably more abundant than areas where the temperature decreased. Spatial variation of soil temperature is a measurement that is of great help in analysis in precision agriculture. These measurements are used to create yield pre-diction models, diagnosis of diseases, and reveal high or low concentrations of temperature temperature concentrations (Martinez and Narducci, 2020). Especially, the predictions about soil temperature at the time of planting of agricultural products are necessary for production management. For example, wheat planting time in Türkiye is made between October and December. As seen in Figure 4, the fact that the trends in Central Anatolia and Western Anatolia increased in these months is an issue that needs attention. This is an important factor in determining the planting time. In a study, it was determined that the germination rate of wheat seeds increased with increasing soil temperature (Fowler et al., 1999). Similar results can be expressed within the 20 cm depth of soil. Trend analysis results based on soil temperature values at a depth of 20 cm are provided monthly in Fig 5.

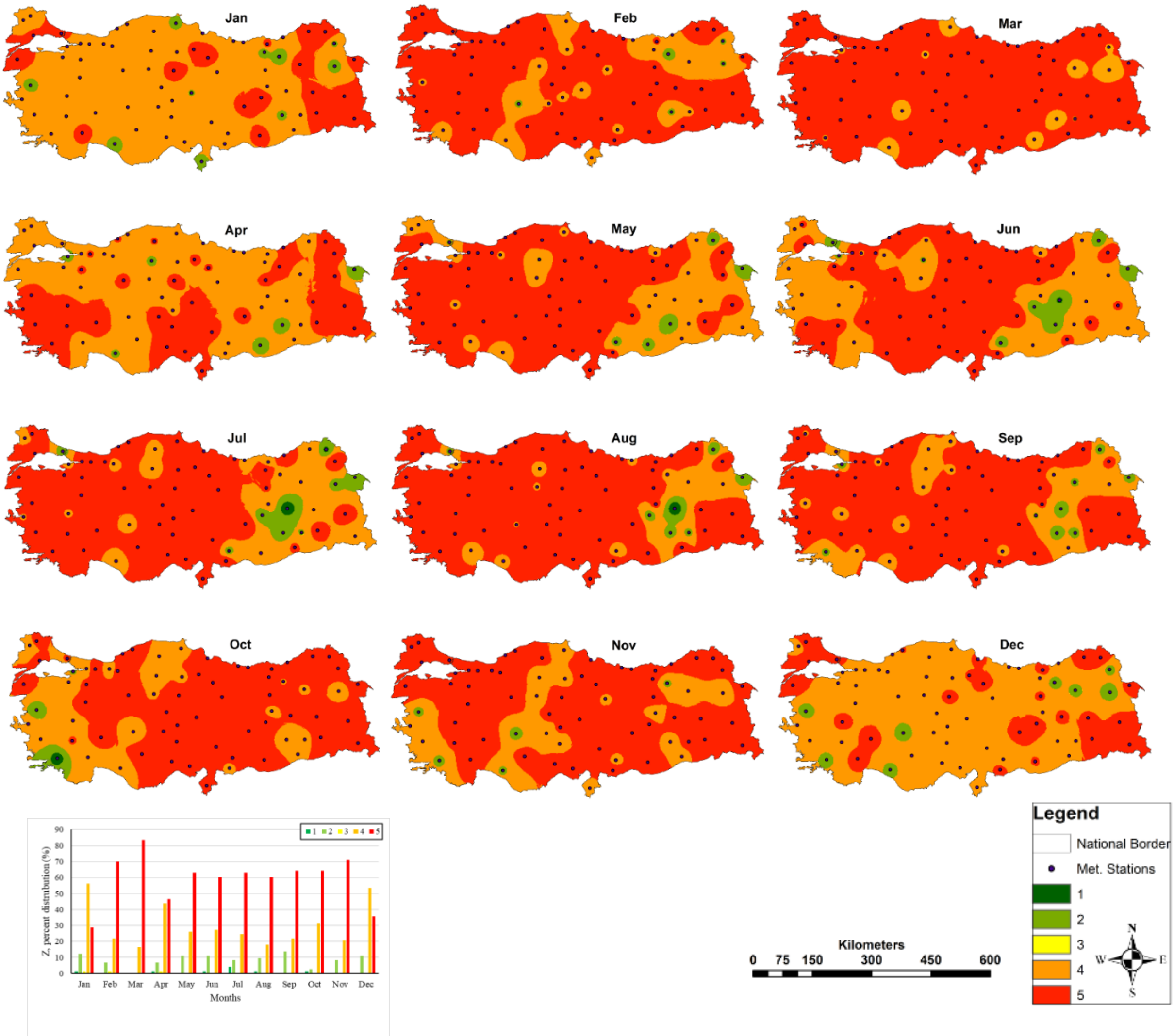

Figure 5. Distribution of trend analysis results of soil temperature at 20 cm depth measured monthly at 73 meteorological stations in Türkiye between 1980-2021 according to the IDW method (1: Significant decreasing trend, 2: Decreasing trend, 3: No trend, 4: Increasing trend, Significant increasing trend)

According to the results of the trend analysis, the highest positive trend in soil temperature measured at 20 cm was determined in Türkiye in March. In March, a Significant Positive Trend (SPT) was detected in 83.56% of the stations where soil temperature measurements were taken. In November, the distribution of the increasing trend in soil temperature in Türkiye was determined to be 71.23% SPT. When the trend analysis distribution map in Figure 5 is examined, it is observed that more than 50% of SPT for 20 cm soil temperature is observed for 9 months. Accordingly, monthly SPT at 20 cm is higher than SPT at 5 cm. On the other hand, the lowest negative trend distribution was determined in July, as in 5 cm. In July, a Significant Negative Trend (SNT) was detected in 4.11% of the stations where soil temperature measurements were taken.

Assessment of soil temperature trend with soil management

Soil surface heat processes such as soil temperature and flux can be represented within a triple block system of total solar radiation-atmosphere-soil. Soil temperature depends on the quantity of heat energy reaching the soil from different sources, the quantity of heat energy lost from the soil through various pathways, and the specific heat of the soil. The correlations obtained between air temperature and soil temperature at present are in line with this statement. However, the effect of heat sources reaching the soil surface or depths of the soil is affected by many factors interactively. Some of these factors include vegetation cover (Song et al., 2013; Ni et al., 2019), soil tillage status (Wierenga et al., 1982; Licht and Al-Kaisi, 2005), soil moisture content (Al-Kayssi et al., 1990; Zhang et al., 2020), topographic conditions (Wu et al., 2016), and specific structural properties of the soil (color, bulk density, organic matter content, texture, etc.) (Elizaberashivili et al., 2010; Martias and Musil, 2012; Sándor and Fodor, 2012). The specific heat of the soil depends on various factors such as vegetation cover, topography, elevation, global solar radiation, air temperature, surface roughness, soil color, water content, and organic-inorganic matter content (George, 2001). Additionally, various factors such as geographic location, soil tillage type, and soil cover affect soil temperature (Elias et al., 2019).

According to the research findings, it is understood that there are increases in soil temperature values at both depths (5 and 20 cm). This situation could adversely affect agricultural production in Türkiye, an important agricultural country, as soil temperature is a leading dynamic physical property that affects evaporation, organic matter decomposition, biological activity, seed germination, and other processes. It is also one of the most sensitive physical properties to management changes (Blanco-Canqui and Ruis, 2020). Some researchers have reported a linear increase in the number of germinating seeds with the elevation of soil temperature to the optimum level. However, it has been reported that germination linearly decreases after further temperature increases (Steinmaus et al., 2000; Bradford, 2002; Onwukaan Mang, 2018). On the contrary, some researchers have reported that increasing soil temperature enhances bioactivity and positively affects the availability of plant nutrients. Stone et al. (1999) reported an increase in maize yield with increasing soil temperature. Similar results have been obtained in studies by Bollero et al. (1996). The effect of soil tillage on soil temperature is significant. Changes in porosity due to soil tillage directly affect heat conduction. Different soil tillage systems applied in agricultural production can affect not only soil temperature but also soil filtration, water content, and soil temperature and significantly alter the soil's physical, chemical, and biological properties (Biberdzic et al., 2020). The need to provide food to the increasing global population has led to intensive agricultural practices involving the conversion of forests and less productive lands into agricultural lands requiring intensive soil tillage and fertilizer use (Haruna et al., 2020).

With the widespread adoption of irrigation in Türkiye, significant changes have occurred in crop patterns, leading to the intensive use of soils for second crop cultivation in many regions. While this case leads to significant increases in agricultural production, unplanned management systems, excessive chemical use, and intensive soil tillage have negative effects on soil's physical properties. Liu et al. (2021) reported that no-tillage and chisel-plowing practices resulted in better outcomes in terms of soil temperature, organic matter content, and total nitrogen compared to conventional tillage and deep tillage. The desire to obtain more yield per unit area leads to excessive field traffic and excessive intervention in the soil due to the use of improper soil tillage methods, resulting in the disappearance of plant residues on the soil surface and an increase in soil temperature. Therefore, it is crucial to implement soil tillage systems that leave a certain amount of plant residue on the soil surface. There are many studies on this subject. Derpsch et al. (2014) stated that crop residues returned to the soil are a critical organic matter input for subsoil, can conserve soil moisture, balance excessive soil temperature, and intensify soil biological activity. Plant residues act as a physical barrier that blocks sunlight and regulates soil temperature fluctuations more efficiently when left on the soil surface compared to when plowed (Thapa et al., 2021a, b). Veiga et al. (2010) reported that changes in soil temperature among soil tillage practices are significant throughout the maize growing season and are dependent on soil cover and soil moisture. Preserving crop residues on the soil surface provides the following benefits to soil quality (Cherubin et al., 2021): increased nutrient cycling (Cherubin et al., 2019), biological activity (Paredes et al., 2015), carbon sequestration (Bordonal et al., 2018), improved structural quality (Castioni et al., 2018), water infiltration (Johnson et al., 2016), and erosion control (Valim et al., 2016). Additionally, stubble can reduce soil temperatures (Awe et al., 2015) but can create better growth conditions for crops by conserving soil moisture.

According to data from the last forty years in Türkiye, significant increases in soil temperatures are observed, parallel to the aforementioned excessive soil tillage and increases in air temperatures. Especially in regions with a semi-arid climate, irregularities in precipitation regimes, coupled with the widespread use of traditional soil tillage practices, lead to significant increases in soil temperatures and also significantly increase the risk of drought. The climate changes led to significant increases in soil temperatures almost throughout the country in February and March. Particularly during the April-November period, when agricultural activities are intensive, positive trend values are concentrated, and significant positive trend (SPT) values are expected to be higher in Central Anatolia due to significantly low rainfall levels. The effect of soil tillage practices on soil temperature increase, especially at a depth of approximately 5 cm, is generally observed at the insignificant positive trend (IPT) level. The intensive use of traditional soil tillage and deep tillage systems, which involve extensive soil disturbance, not only leads to excessive intervention in the soil but also causes a significant positive trend (SPT) in soil temperatures at a depth of 20 cm from February to November in almost the entire country.

The soil temperature values used in the study are values measured at meteorological stations under controlled conditions. It should be noted that the effect of agricultural practices mentioned above may further increase or decrease soil temperature values. Therefore, further research is needed on how soil temperature can be affected by agricultural practices. In Türkiye, soil tillage systems leave little crop residue on the soil surface. This situation, along with wind and water erosion, leads to sudden changes and increases in soil temperature levels. Therefore, protective soil tillage systems that leave more crop residue on the soil surface need to be implemented rapidly. Studies should be conducted to disseminate the most appropriate method among reduced tillage, strip tillage, and no-till (direct seeding) systems, considering the soil type, climate characteristics, and crop variety, to increase their usage in agricultural production further.

Rising trends in soil temperature can favor some changes in soils. The exchange in evaporation with soil-moisture balance can be given as a good example. Because soil surface temperature is near related to soil evaporation rate and soil evaporation stages (Qiu and Ben-Asher, 2010). Many researchers (Reginato et al., 1976; Hatfield et al., 1983; Krideg et al., 2008) have urged that soil temperatures can be used to estimate evaporation. The occurrence of high rates of evaporation provides the development of significant soil problems such as salinization in arid and semiarid regions. Today, at that place are salinity and sodicity problems in 1,518,722 hectares of land in Türkiye (Sönmez, 2011). Increasing trends in soil temperature can affect this amount to increase more. Changes in soil temperature as well affect the hydraulic attributes of soils (Grant and Bachmann, 2002). For example, changes in soil temperature impact soil particles, soil porosity, and the interaction surface between liquid and solid, specially more importantly in heavy loamy soils with high clay content. Increases in temperature can reduce interparticle the bond strength, which, when compounded with differential thermal expansion between mineral particles and water, can cause a decrement in void ratio. expansion of particles also causes a decrease in specific surface area, which means reductions in the water retention capacity of the particles (Gao and Shao, 2015). The increasing temperature trends obtained in this study showed up that more measures should be adopted the future concerning the protection of soil moisture in agricultural and pasture fields. There's a close relationship between soil warming and biochemical events. According to a study, it was shown that caused changes in organic carbon stability, changes in microbial structure and increased decomposition reaction rates a 2 °C soil warming at 25 cm soil depth over a 10-year period (Cheng et al., 2017). In fact, due to climate, topography, intensive agricultural practices and improper soil management, for soils are poor in terms of organic matter in many regions in Türkiye (Aydın et al., 2016; Kapur et al., 2017; Demir and Mirici, 2022). The fact that a large part of the soil temperature trend results given to Figure 3 are increasing may make the organic carbon stock further still dramatic in the soil. In many studies, they are especially climate change of estimated that soil organic carbon will decrease imputable various factors (Lal, 2004; She et al., 2022; Wang et al., 2023). We anticipate that our research findings can inform future soil management policy making in this region. We think that our research findings can be applied as a tool in planning the best soil management practices for nowadays and the future in Türkiye.

CONCLUSIONS

According to the trend analysis conducted using the soil temperature values of 73 meteorological stations in Türkiye between 1980 and 2021, a predominantly positive increase has been observed. Although negative trends have been detected in some locations, the increase in temperature has been much more pronounced. Significant correlations have been found between soil temperature and air temperature values for the same stations. However, agricultural practices such as intensive soil cultivation can further increase the effect of soil temperature. Changes in soil temperature in Türkiye, an important agricultural country, may have adverse effects on agricultural production. In many studies conducted on this subject, it has been reported that with the increase in soil temperature, irregularities occur in germination, nutrient availability, and soil-water balance. The most important of these irregularities is the disruption of the balance in soil-plant water relations. The germination performance of seeds sown in the soil for the cultivation of winter crops in October and November and summer crops in March and April is closely related to this balance. Positive trends will lead to soil moisture loss. Consequently, there will be a much greater demand for freshwater sources used for irrigation. The most appropriate soil management practices must be carried out meticulously to minimize the threats posed by the increase in soil temperature.

Acknowledgements

Meteorological parameters are obtained from the General Directorate of Meteorological Services. We would like to thank for their contribution.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Author Contributions

Yasin DEMİR :*The main idea of the study, data collection, data analysis, mapping, writing*

Azize DOĞAN DEMİR: *statistical analysis, discussion and interpretation of findings, writing*
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Article History

Submission received:	09.12.2024
Revised:	09.02.2025
Accepted:	12.02.2025

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