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Research Article

Impacts of Soil Temperature on Apricot Productivity in Malatya, Türkiye: A Longitudinal Analysis Using Inverse Distance Weighting

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Abstract: This longitudinal study analyzes the impact of soil temperature on apricot productivity in Malatya, Turkey, from 2004 to 2022. Utilizing Inverse Distance Weighting (IDW) to correlate detailed soil temperature maps with apricot yield and production data, we identify significant temperature-dependent variations in apricot yields. Our findings reveal that optimal soil temperature management is crucial for maximizing apricot productivity, as deviations from ideal soil temperatures correlate strongly with yield fluctuations. Specifically, periods of increased soil temperatures generally correspond with higher productivity, highlighting the delicate balance required for optimal apricot cultivation. This research underscores the importance of integrating climate considerations into agricultural planning and offers valuable insights for developing adaptive strategies to enhance apricot production in the face of global climate variability. By mapping the spatial and temporal dynamics of soil temperature and its impact on apricot yield, this study contributes to the broader discourse on sustainable agricultural practices and the economic resilience of the apricot sector in Malatya.

Keywords: Soil temperature, apricot productivity, Inverse distance weighting, geospatial analysis, Malatya-Türkiye.

1. Introduction

Soil temperature is a crucial environmental factor influencing seed germination, plant growth, and root development, significantly affecting agricultural productivity and ecosystem dynamics. The thermal condition of the soil directly impacts the metabolic rates of plants and microbial activity within the soil, which in turn affects nutrient cycling and availability for plant growth. Optimal soil temperatures vary among plant species, but are generally required for effective seed germination and root proliferation, critical for establishing robust plant stands (Yang et al., 2021). Soil temperatures below the optimal range can delay germination and reduce seedling vigor, leading to uneven crop stands and increased vulnerability to diseases and pests. Conversely, excessively high soil temperatures can impair root development and function, reduce water and nutrient uptake, and ultimately lead to plant stress and lower yields (Xiao and Weng, 2007). The intricate balance within the soil environment underscores the necessity for precise temperature management to ensure agricultural success (Bristow, 1988; Qian et al., 1997; Kang et al., 2000; Al-Kaisi and Yin, 2003).

The relationship between soil temperature and plant development extends beyond the initial growth phases, influencing the entire life cycle of the plant. For instance, soil temperature affects phenological events such as flowering, fruit set, and maturation, with significant implications for the timing and quality of crop production. In perennial crops, soil temperature can influence dormancy break and budburst, thereby dictating the start of the growing season and susceptibility to late frost damage. Moreover, variations in soil temperature, driven by seasonal changes and land management practices, can alter the spatial and temporal patterns of plant communities and ecosystems. This relationship highlights the broader implications of soil temperature regulation, not just for individual crop success but for the sustainability of entire agricultural systems and biodiversity within ecosystems. Managing soil temperature effectively becomes a cornerstone in adapting to the challenges posed by climate change and ensuring food security (Prasad et al., 2008; Wheeler et al., 2000; Sarvas, 1974; Anderson et al., 2012; Kaspar and Bland, 1992; Zhang et al., 2015).

Transitioning from the broader agricultural implications of soil temperature, we delve into the specific context of Turkey, where climatic conditions, especially soil temperature, play a pivotal role in shaping agricultural productivity and horticultural practices. The dynamics of soil temperature intersect with the phenological cycles of plants to influence growth patterns and yields (Wheeler et al., 2000). In regions like Turkey, where agriculture and fruit cultivation are integral to the national economy, the study of soil temperature dynamics becomes crucial. The impact of soil temperature on agricultural yield extends beyond the biological aspects of crop growth, affecting economic outcomes and market stability. Thus, understanding the nuances of soil temperature variations and their effects on plant growth is essential for developing strategies that ensure consistent and high-quality agricultural output (Balcıoğlu, et al., 2022; Myneni et al., 1997; Peng et al., 2014; Zhang et al., 2007; Solanky et al., 2018).

Within the global agricultural landscape, Turkey emerges as a dominant force in apricot production, significantly influencing international markets and trade dynamics (Ünal, 2010). The strategic importance of Turkey's apricot industry, particularly in regions like Malatya, is underscored by the country's vast exports and the economic benefits derived from this agricultural sector (Sarıbaş, 2012; Öztürk and Karakaş, 2017). The climatic conditions and soil structure in Malatya provide an optimal environment for apricot cultivation, contributing to Turkey's leading position in the global market (Karataş, 2016). However, this success is not without its challenges, as fluctuations in soil temperature, particularly during critical growth phases, can profoundly affect production outcomes. The susceptibility of apricots to temperature variations, especially during flowering and fruit set stages, highlights the critical role of environmental factors in determining crop yields and quality. Addressing these challenges through targeted research and adaptive agricultural practices is essential for maintaining and enhancing the productivity of the apricot sector (Hatun, 2010; Kreyling et al., 2015; Bergjord Olsen et al., 2018; Turkish Statistical Institute, 2022).

This study is centered around the Malatya province, a key region in Turkey's apricot cultivation sector. By examining the "Monthly Average 100 cm Soil Temperature (°C)" from 2004 to 2022, data provided by the General Directorate of Meteorology (MGM) and the Turkish Statistical Institute (TÜİK), we aim to elucidate the intricate relationship between soil temperature fluctuations and apricot productivity. Employing the Inverse Distance Weighting (IDW) method to analyze this extensive dataset allows us to correlate apricot yield and production statistics with temperature variations, providing a detailed perspective on the climatic influences affecting apricot cultivation. This research not only highlights the specific climatic challenges faced in Malatya but also extends its implications to the wider discourse on sustainable agricultural practices and economic resilience in the face of climate variability. By incorporating critical geographical variables such as aspect and elevation, our study offers a holistic view of the diverse factors influencing agricultural outputs, thereby underscoring the importance of integrated agricultural planning and adaptive management strategies for enhancing productivity and sustainability in the apricot sector.

2. Materials and Methods

The study area is located in the Upper Euphrates Basin of the Eastern Anatolia Region, within the province of Malatya (Ağaldağ, 1988). Geographically, Malatya is bordered by Sivas and Erzincan to the north, Adıyaman to the south, Elazığ and Diyarbakır to the east, and Kahramanmaraş to the west. It spans an area of 12,412 km² and is located between latitudes 35°54'N and 39°03'N, and longitudes 38°45'E and

39°08'E (Governorate of Malatya, 2014) (Fig 1). The region's topography, influenced by the Alpine orogeny and subsequent tectonic activities during the late Tertiary and early Quaternary periods, features various uplifts and depressions. Notable topographic features include elevations reaching up to 1800 meters in areas between the Malatya Basin and Malatya Mountains (2550 m) to the south, and between the Doğanşehir-Polat Depression and Nurhak Mountains (2700 m). The western terrain is marked by a pronounced elevation of up to 1500 meters between the valley floors of Tohma and Ayvalıtohma streams and the surrounding mountainous masses. The region also hosts limestone mountains such as Mount Samur (1922 m), Mount Cuma (2029 m), Mount Akbabaçalı (2164 m), and Mount Hezanlı (2283 m), which dominate this section of Malatya, towering over adjacent plateau areas with elevations exceeding 500 meters. Malatya's climate is characterized by cold, prolonged winters and hot, dry summers, with significant diurnal and seasonal temperature variations due to its inland, elevated position. The annual average temperature is 13.7 °C, with an average annual precipitation of 383.5 mm (MGM, 2021), creating conditions favorable for apricot cultivation (Anderson and McNaughton, 1973). The precipitation patterns in the region are influenced by the mountain ranges extending in an east-west direction. The Southeastern Taurus Mountains block southward moving fronts, increasing precipitation in their leeward areas while creating drier conditions in the Malatya depression due to rain shadow effects (Atalay, 2003).

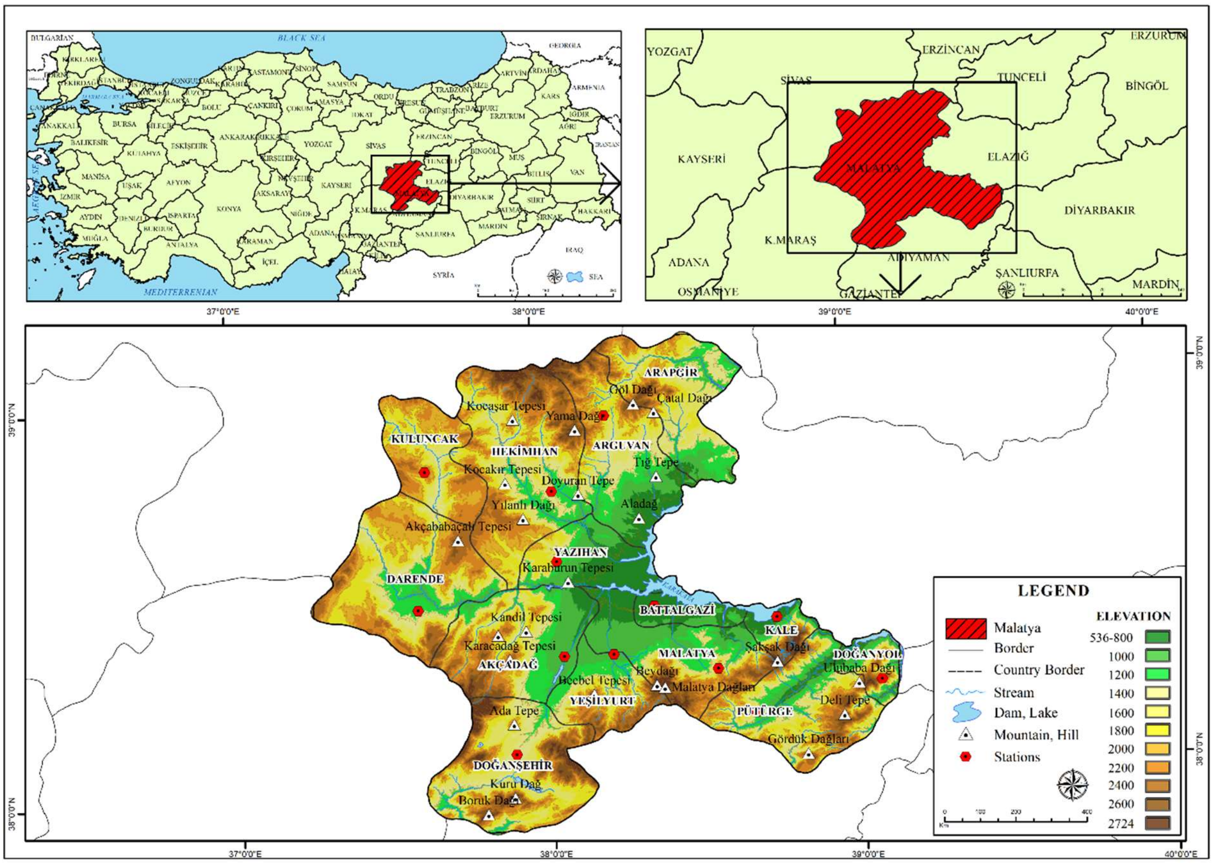

Figure 1. Geographical and physical map of Malatya Province.

Regarding agricultural land use, Malatya allocates 34% of its total area to agricultural lands and 47% to pasture and meadow lands, which are above the national average for Turkey. The total arable land in Malatya, ranging from Class I to Class IV, comprises 402,310 hectares, whereas land classified between Class V and Class VIII accounts for 23,140 hectares (FKA, 2010) (Table 1). Soil classification in the study area plays a crucial role in understanding the agronomic potential and constraints of Malatya. The soil types, ranging from highly fertile Class I soils ideal for intensive agriculture to Class VIII soils which are mostly marginal and suitable for limited pastoral activities, significantly influence the types of crops that can be grown and the methods of cultivation that can be employed. Knowledge of these soil characteristics is essential for optimal land management and sustainable agricultural practices. This information not only aids in maximizing agricultural output by informing crop selection and agricultural strategies but also helps in mitigating the risks associated with soil degradation and erosion, ensuring the long-term productivity of the land (Özüpekçe, 2021).

Table 1. Soil classification of the study area (FKA, 2010).

I. Class	70.177 Ha
II. Class	81.399 Ha
III. Class	126.517 Ha
IV. Class	124.217 Ha
V. Class	0
VI. Class	14.105 Ha
VII. Class	9.035 Ha
TOTAL	425.450 Ha

2.1 Data Sources and methodological framework

In this research, the methodology incorporates advanced geospatial analyses facilitated by the utilization of QGIS V3.36.2 software and ArcGIS Pro 2.8 software, as developed by ESRI. These tools were instrumental in calculating soil temperatures and in the subsequent generation of detailed apricot production and yield maps. A thorough review of the existing scholarly literature revealed a prevalent correlation between vegetative output and surface temperatures, validating the approach undertaken in this study.

Specifically, surface temperature datasets were identified as predominantly derived from either Landsat or MODIS satellite imagery. In alignment with established academic precedents, this study leveraged MODIS MOD11A2 and MOD11B3 satellite images sourced from the Earth Data website. These images were meticulously processed to represent surface temperatures accurately (Duan et al., 2017). However, due to their inherent limitations in reflecting only instantaneous surface temperature values and their lack of depth in representing soil temperatures, these images were ultimately not utilized for the core analysis. This decision underscores the study's commitment to precision and relevance, particularly as soil temperature exerts a more pronounced influence on plant development than mere surface readings, a fact supported by extensive biochemical and ecological evidence (Rajeshwari and Mani, 2014; Tan et al., 2020).

To achieve a more nuanced understanding and ensure methodological rigor, alternative data were soughtda. The study thus utilized long-term temperature records provided by the Turkish State Meteorological Service (MGM), chosen for their comprehensive temporal scope and reliability (Awais et al., 2022). These records span from 2004 to 2022 and include detailed "Monthly Average 100 cm Soil Temperature (°C)" datasets, offering a robust framework for the analysis. The data from approximately nine meteorological stations were synthesized through the Inverse Distance Weighting (IDW) interpolation method, facilitating the creation of nuanced soil temperature maps over a nineteen-year period (Yenipınar et al., 2021). The methodological integrity of this approach was subsequently validated through rigorous field study comparisons.

Complementing the climatic data, apricot production and yield statistics were procured from the Turkish Statistical Institute (TÜİK), ensuring a solid empirical basis for this research. These statistics, which also span the years 2004 to 2022, provided a vital comparative dimension for the geospatial analysis, enabling an integrated assessment of climatic impacts on agricultural outputs. The selection of these specific data sources and the analytical techniques employed reflect the study’s dedication to scientific accuracy, relevance, and the pursuit of comprehensive insights into the interplay between soil temperature and apricot productivity.

2.2. Generation of Soil Temperature Maps

In this study, we employed the Inverse Distance Weighting (IDW) method to analyze and estimate the values at unknown points based on known values from neighboring points. The IDW method operates on the principle that the influence of a known point decreases with increasing distance from the point being estimated. This relationship is quantified by the distance and the magnitude of the neighboring values, with the influence diminishing as the distance increases (Güler and Kara, 2007).

The IDW approach is particularly suited for regional value estimation as it utilizes the distances between points as weights in calculating the values of unknown points. The fundamental assumption of the IDW method is that points closer to the area of interpolation exert more influence than those farther away, ensuring a high degree of local accuracy (Shepard, 1968; Güler & Kara, 2007; Loyd, 2007).

To generate detailed soil temperature maps, we leveraged long-term soil temperature data to enhance the analytical rigor of our Inverse Distance Weighting (IDW) analysis. Data were collected from seven strategically located stations measuring soil temperature across the province of Malatya, as detailed in (Table 2). Considering the limited number and uneven spatial distribution of stations, interpolation methods supported by GIS have been utilized to continuously generate soil temperature data across the entire area.

Inverse Distance Weighting (IDW) is a well-regarded spatial interpolation method often utilized in the creation of continuous surface models, particularly useful in fields such as environmental science and geology. The principle behind IDW is to estimate values at unsampled locations by taking a weighted average of the values from nearby known points. The weights are inversely proportional to the distance fcomplrom the known point to the unknown point, emphasizing that nearer observations influence the prediction more than those farther away. This method, supported by the Geostatistical Analyst tools in GIS software, relies on the assumption that points closer to each other are more alike than those further apart, thus the impact of a sampled point decreases as the distance increases. The general form of the IDW equation reflects this relationship by assigning greater importance to closer points through a mathematical formulation that integrates both the distance factor and the known values (Bartier and Keller, 1996; Jones et al., 2003; Huang et al., 2011).

$$\hat{Z}\ (x_0) = \sum_{i=1}^{n} z(x_i).d_{ij}^{-p}\ /\ \sum_{i=1}^{n} d_{ij}^{-p} \quad (1)$$

Here, Z represents the interpolated value at a grid node, Z_i denotes the neighbouring data points, and d_{ij} corresponds to the distances between the grid node and these data points.

Table 2. Data were collected from soil temperature measurement stations located across the study area.

Station ID	Lat/Long	Station Elevation (m)	Meteorological region
17706 Akcadag / Sultansuyu TIGEM	38°03E/38°20N	864	13. Region (Malatya)
17764 Arapgir	38°29E/39°02N	1200	13. Region (Malatya)
18187 Battalgazi / Meyvecilik TIGEM	38°21E/38°27N	738	13. Region (Malatya)
17842 Darende / Balaban	37°35E/38°28N	1098	13. Region (Malatya)
17872 Dogansehir	37°53E/38°05N	1223	13. Region (Malatya)
17199 Malatya	38°13E/38°20N	950	13. Region (Malatya)
17845 Malatya / Kale	38°45E/38°24N	722	13. Region (Malatya)

The average soil temperature data (°C), collected from these stations, were then incorporated into the Attribute Table associated with their respective locations (Jiang and Tian, 2010). Using the Geostatistical Analyst tool within ArcGIS, we created soil temperature maps that span a period of 19 years. These maps were generated using interpolation methods that utilized annual data sets, thereby providing a comprehensive spatial representation of soil temperature variations across the region (Hulley et al., 2019).

2.3. Maps for Apricot Yield and Production Analysis

The process of mapping apricot yield and production in the province of Malatya began with the collection of yield and production data from the Turkish Statistical Institute (TÜİK), complemented by CORINE 2018 data detailing vineyard and garden areas. Additional precision was achieved by identifying apricot orchard locations via Google Earth Pro. These locations were initially saved in KMZ format and later converted to shapefile (SHP) format using ArcGIS Pro for detailed geospatial analysis. The study further leveraged multiple data sources to analyze the spatial distribution of apricot plantations, including CORINE 2018 land cover data, forest management planning data from the General Directorate of Forestry, and satellite imagery, along with field surveys. The integrated approach in the ArcGIS platform facilitated the transformation of identified locations into SHP format, enabling the examination of the relationship between soil temperature and apricot cultivation by overlaying production and yield data onto the GIS maps.

The produced maps, segmented by the districts of Malatya, were integrated with the aforementioned production and yield data. This integration facilitated the generation of comprehensive apricot production and yield maps spanning the years 2004 through 2012. Following significant administrative boundary changes in 2013, which resulted in the central district of Malatya being redefined to include the Battalgazi and Yeşilyurt districts, it became necessary to redraw the boundaries within the ArcGIS environment to reflect these changes.

The mapping procedures were then reapplied within these new boundaries, utilizing additional data obtained from digital elevation models and hillshade analyses to enhance the maps' accuracy and detail. As a result, comprehensive apricot yield and production maps covering the extended period from 2013 to 2022 were produced, thus providing a complete visual representation of 19 years of apricot agriculture in Malatya.

4. Results

A total of 57 maps covering 19 years were generated to analyze the spatial distribution of apricot plantations and assess the impact of soil temperature on apricot yield. These maps, displayed at intervals of 9-10 years starting from 2004, facilitated a comprehensive long-term analysis.

Consistent with global trends, apricot production in Malatya is significantly impacted by climatic adversities, particularly late spring frosts and early autumn frosts that recur annually or biennially. These conditions result in notable declines in both yield and overall production. An analysis of production-yield and soil temperature data, as depicted in Figures 2, 3, and 4, identifies a marked reduction in production and yield rates for the year 2004 compared to subsequent years. This reduction is primarily attributed to adverse climatic events, specifically late spring frosts, which significantly affect fruit viability (Sunkar et al., 2013). Furthermore, the broader context of stone fruit cultivation in Turkey underscores the susceptibility of certain fruit varieties to extreme temperature fluctuations, which can lead to significant damage to flowering buds, adversely affecting yields (Küden et al., 1998). A detailed examination of the period between 2004 and 2012 reveals that the districts of Akçadağ, Arapgir, Arguvan, Battalgazi, Darende, Doğanşehir, Doğanyol, Kale, Merkez, Pütürge, Yazıhan, and Yeşilyurt recorded their lowest production and yield figures in 2004.

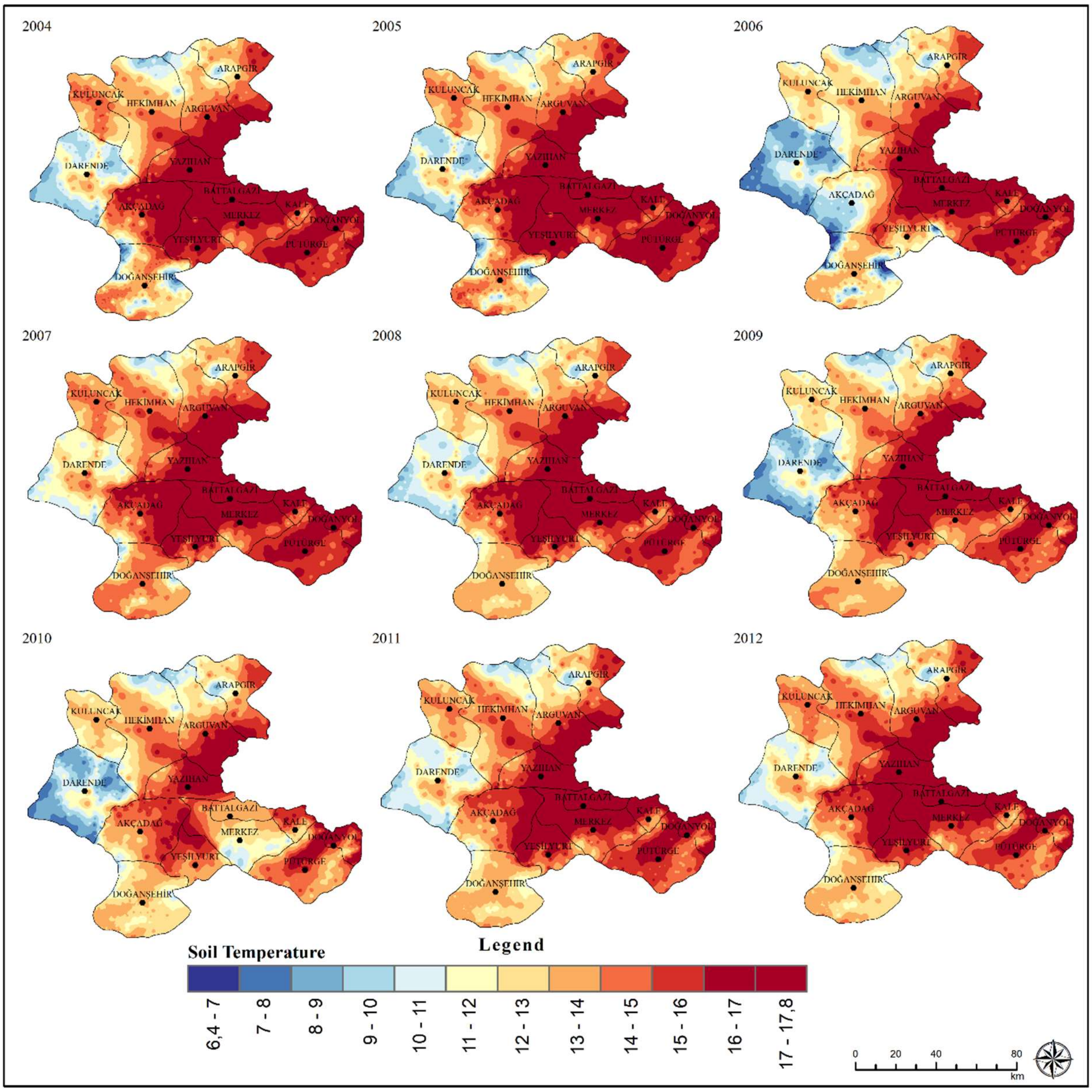

Figure 2. Soil temperature map of Malatya (ºC), 2004-2012.

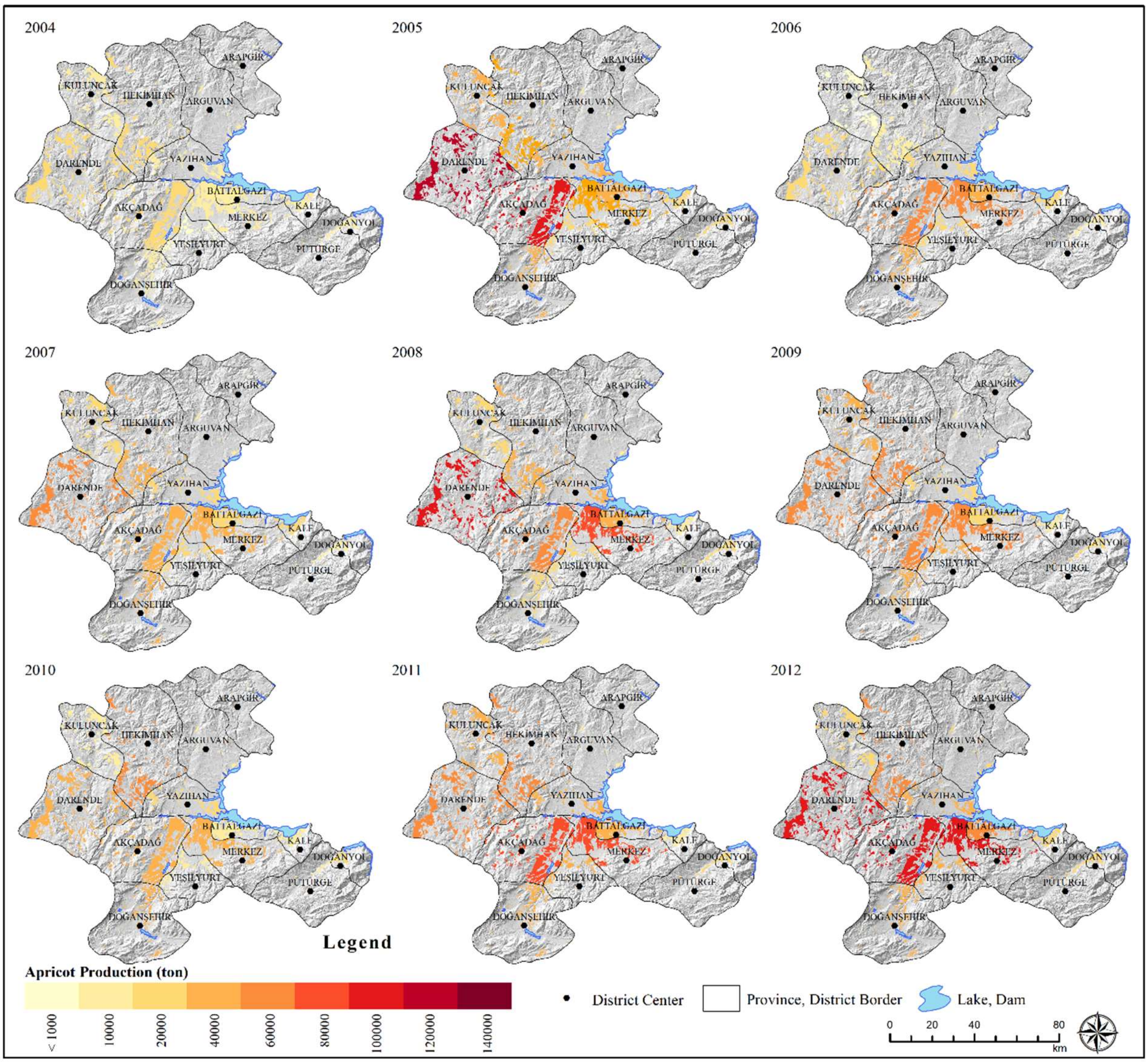

Figure 3. Apricot production in Malatya (in Tons), 2004-2012.

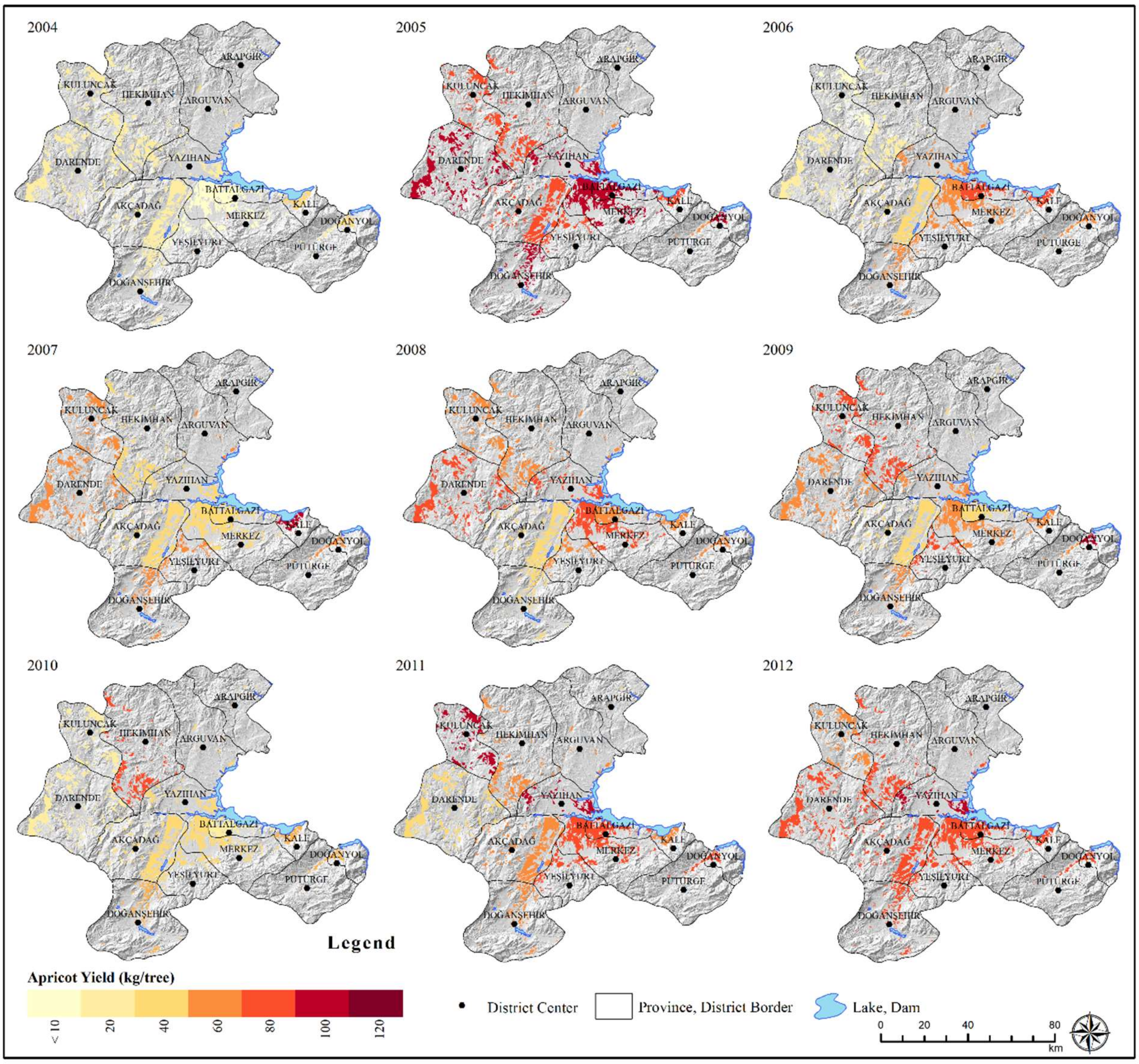

Figure 4. Apricot yield per tree in Malatya (kg), 2004-2012.

In the analysis of the apricot production and yield for 2005, the highest production within the decade was recorded at 109,326 tons in the Darende district. Concurrently, yields in the Battalgazi, Doğanşehir, Doğanyol, and Merkez districts ranged from 90-97 kg per tree. A significant increase in yield was observed across Malatya during this year. Soil temperature data further corroborated these findings, indicating an upward trend particularly in the southern and southeastern regions of Malatya.

The 2006 data analysis revealed a general decrease in soil temperatures across the western part of Malatya, which variably affected apricot yields in different districts. Notably, Arapgir district showed a unique increase in both yield and production, contrasting sharply with the Arguvan district, where yield levels remained consistent with the previous year. Conversely, Hekimhan district reported a minimal yield of 1 kg per tree and a total production of 298 tons, marking it as one of the lowest outputs within the period. Kuluncak district also recorded low figures, with a yield of 13 kg per tree and a production of 9,191 tons.

The year 2007 stood out for recording the highest soil temperature values within the nineteen-year period analyzed. Despite rising temperatures in the northern part of Hekimhan, notable increases in apricot production and yield were observed particularly in the Kale and Yeşilyurt districts. Across the province, production figures varied between 40,000 and 60,000 tons, while yields maintained within the range of 40 to 80 kg per tree, reflecting district-specific variations in agricultural productivity.

In 2008, an increase in soil temperatures was observed in the Akçadağ, Yeşilyurt, Battalgazi, and Merkez districts. This year recorded apricot productions of 42,526 tons in Akçadağ, 20,850 tons in Battalgazi, 16,338 tons in Yeşilyurt, and 63,000 tons in Merkez. The highest yields were reported in Doğanyol district at 60 kg per tree, while yields in Kale, Pütürge, Yeşilyurt, and Merkez districts reached 70 kg per tree. Despite a slight decrease in soil temperatures, Darende district experienced an increase to 89,420 tons of production and a yield of 68 kg per tree.

In 2009, the districts of Akçadağ, Arapgir, Battalgazi, Doğanşehir, Hekimhan, Kuluncak, and Yeşilyurt reported increases in both yield and production compared to the previous year, with Doğanyol district achieving the highest apricot yield recorded from 2004 to 2012 at 100 kg per tree. Conversely, production and yield amounts in Arguvan, Battalgazi, Darende, Kale, Merkez, Pütürge, and Yazıhan districts declined, although Pütürge maintained a stable yield. The 2009 soil temperature map, as depicted in Figure 2, shows a temperature decrease in the northern, northwest, and western parts of the province compared to 2008.

The observations from 2010 highlight a period characterized by notably low soil temperatures across Malatya, which corresponded with a widespread reduction in apricot yield and production across all surveyed districts. This trend substantiates the hypothesized correlation between soil temperature fluctuations and apricot production metrics. Subsequent data from 2011 and 2012 indicate a recovery in surface temperatures, followed by a significant increase in agricultural output.

Detailed assessments for the year 2011 demonstrate a considerable increase in apricot production, culminating in a total output of 409,646 tons and an aggregate yield of 871 kg per tree across Malatya. This positive trend continued into 2012, with recorded increases elevating the total production to 510,000 tons and yield to 941 kg per tree, thereby underscoring a pronounced recovery and growth in apricot agriculture following the climatic challenges of 2010.

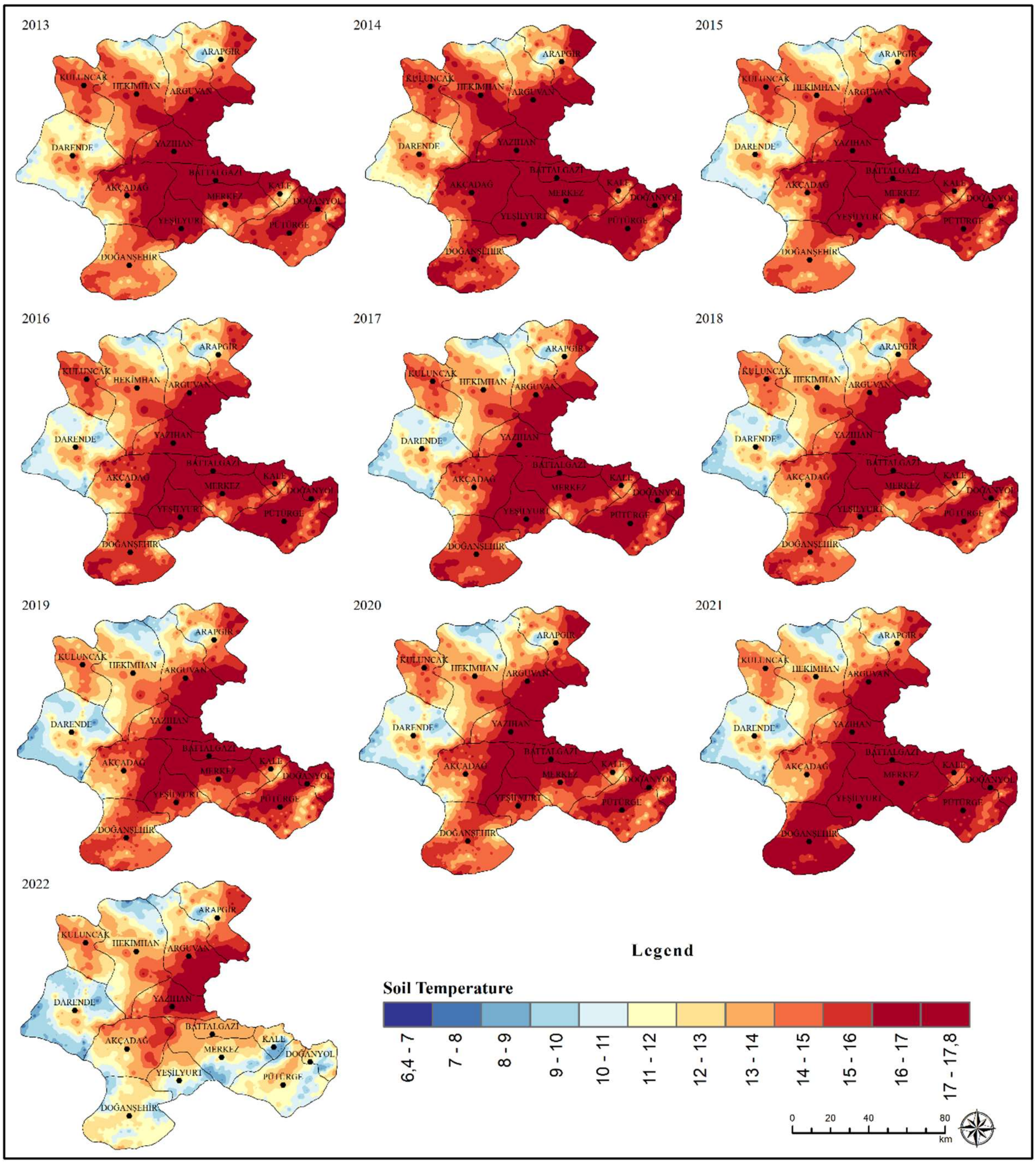

Figure 5. Soil temperature map of Malatya (ºC), 2013-2022.

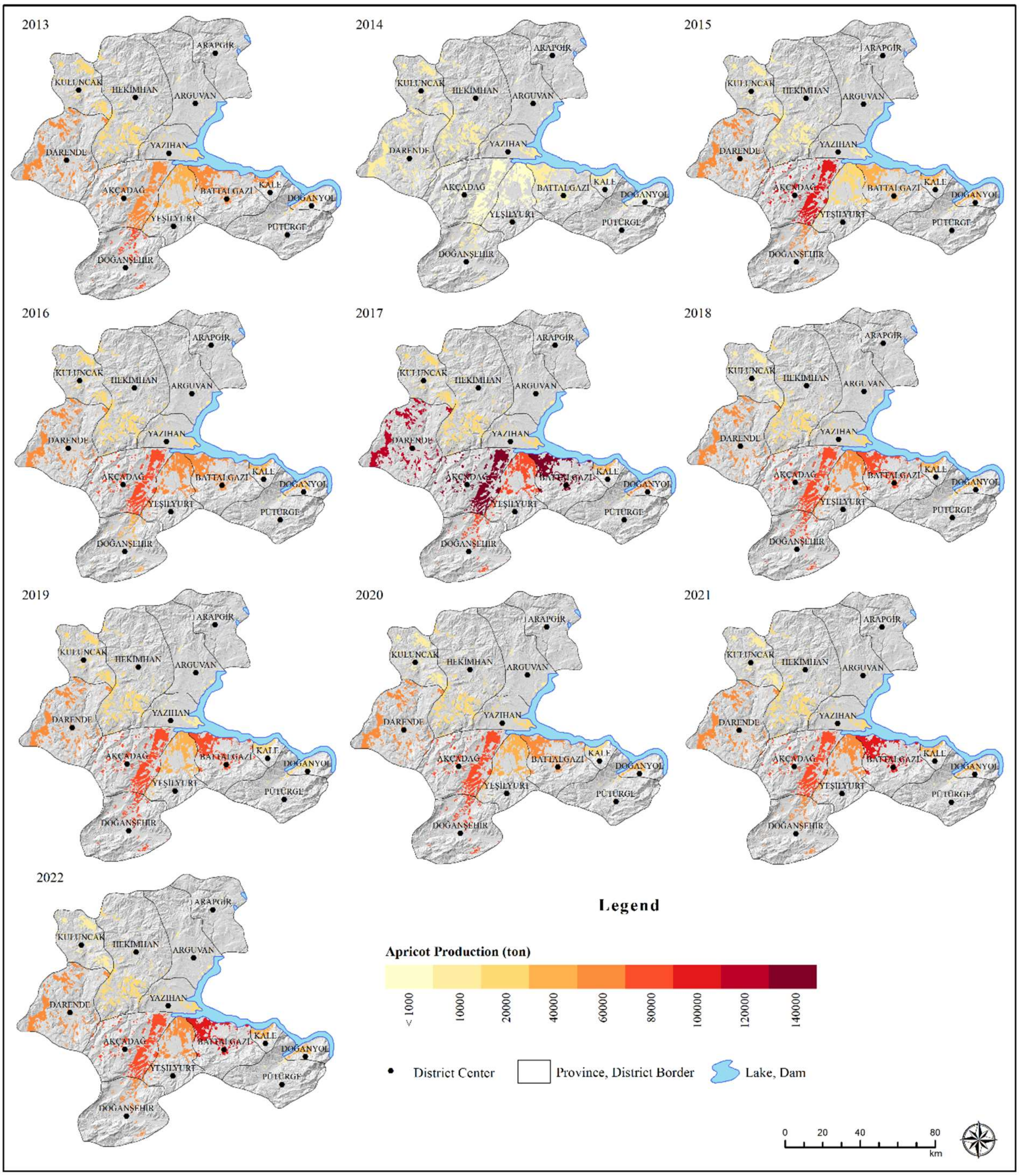

Figure 6. Apricot production in Malatya (in Tons), 2013-2022.

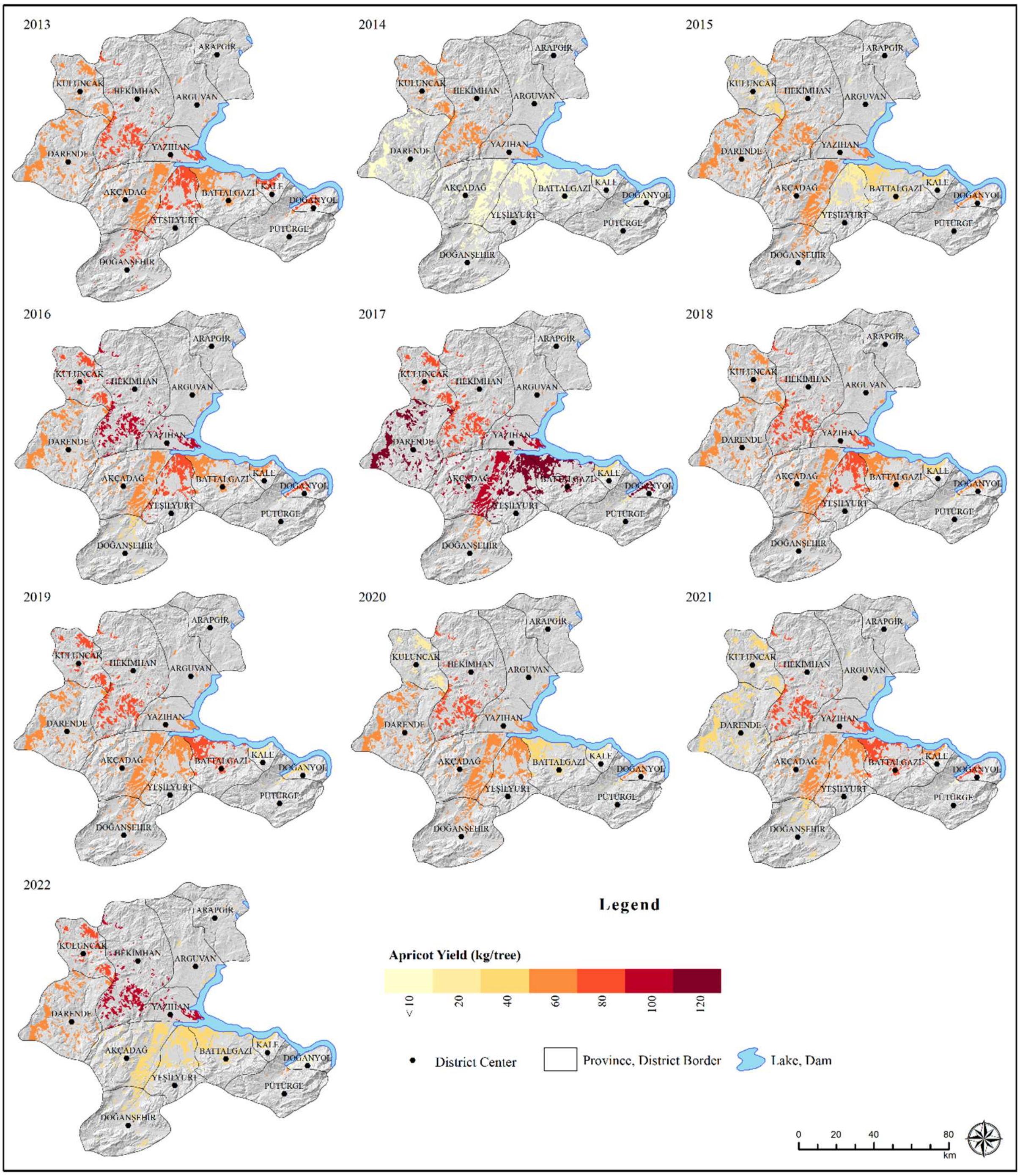

Figure 7. Apricot yield per tree in Malatya (kg), 2013-2022.

Analysis of soil temperature trends from 2013 to 2022, as depicted in Figure 5, clearly demonstrates that annual surface temperature variations were significantly influenced by frost events, occurring either annually or biennially. Notably, the year 2013 experienced significant elevations in surface temperatures, particularly in the Hekimhan, Yazıhan, Yeşilyurt, and Doğanşehir districts. These temperature increases are meticulously illustrated in the corresponding soil temperature map shown in Figure 5. Concurrent analyses, presented in Figures 6 and 7, indicate that the peak of apricot production during this period occurred in Doğanşehir, which was also accompanied by substantial increases in yields across the Hekimhan, Yazıhan, Yeşilyurt, and Doğanşehir districts. This correlation underscores the profound impact of soil temperature fluctuations on apricot yield and underscores the importance of mitigative strategies against frost risks

The temporal analysis for the period from 2004 to 2022 highlights 2014 as a year with anomalously high soil temperatures, coinciding with the lowest decadal yields and production figures, recorded at 38,654 tons and 162 kg per tree, respectively. This substantial deviation is primarily attributed to adverse frost events that severely impacted apricot production. In the subsequent years of 2015 and 2016, a marked escalation in soil temperatures was observed, particularly in the districts of Darende, Akçadağ, Yeşilyurt, Battalgazi, and Doğanyol. This increase in temperature correlated strongly with significant improvements in apricot yield and production within these regions. Notably, the zenith of yield and production during this biennial period was systematically observed in Darende, Akçadağ, Yeşilyurt, and Battalgazi, clearly demonstrating the critical influence of elevated soil temperatures on apricot agricultural outcomes.

In 2016, a detailed comparative analysis revealed a marginal increase in soil temperatures in the southern parts of the Pütürge district compared to the previous year. Simultaneously, the Doğanşehir district experienced a significant rise in temperatures, which fluctuated between 14-15 °C. This increase in temperatures directly impacted agricultural outputs, with Pütürge recording a substantial increase in yield from 44 kg to 89 kg per tree, and a corresponding rise in production from 8,503 tons to 17,324 tons. Doğanşehir also demonstrated improved agricultural performance, with yields increasing from 60 kg to 66 kg per tree, and production escalating from 26,022 tons to 29,084 tons. These findings underscore the sensitive interplay between soil temperature variations and apricot yield and production in these regions.

In 2017, the Battalgazi district reached a historical peak in apricot yield and production, recording an unprecedented 138,600 tons, the highest in the decade. This surge in productivity was mirrored in the Doğanşehir, Yeşilyurt, Arguvan, Arapgir, and Akçadağ districts, all of which registered remarkable levels of yield and production. In contrast, the southeastern sector of Hekimhan experienced a decrease, with thermal gradients observed across the district-temperatures ranged from 10-12 °C in the northwest to 14-16 °C in the northeast and southern areas. This temperature variability contributed to a decrease in yield from 43 kg per tree in 2016 to 40 kg per tree in 2017, and a drop in production from 31,998 tons to 30,400 tons. Despite these local challenges, an overarching analysis across Malatya revealed a significant increase in soil temperatures, which correlated strongly with enhanced apricot production and yield across the province, demonstrating a clear linkage between soil temperature fluctuations and agricultural productivity.

In 2018, the soil temperature profile across Malatya showed a consistent pattern with the previous year, although minor localized fluctuations were primarily noted in Doğanşehir, where temperatures ranged between 14-15 °C. The following year, 2019, saw a decrease in regional soil temperatures, particularly within the Hekimhan and Kuluncak districts as shown in Figure 5. In Hekimhan, temperatures varied between 11-13 °C, while Kuluncak experienced similar temperatures ranging from 12-13 °C. In contrast, the districts of Yazıhan, Yeşilyurt, Battalgazi, Kale, Pütürge, and Doğanyol witnessed a slight increase in soil temperatures compared to the previous year, with values between 15-17 °C. Noteworthy increases in soil temperatures were also observed in the northern, southern, and central sectors of Doğanşehir, consistently recorded between 14-15 °C.

A comprehensive analysis, as depicted in Figures 6 and 7, covering the interval between 2018 and 2019, reveals that yield metrics in Akçadağ, Arguvan, and Yeşilyurt remained consistent, despite observing a general trend of yield reduction in other districts. During this biennial period, incremental enhancements in yield and production were notably documented in Akçadağ, Battalgazi, Darende, Doğanyol, Kale, and Yeşilyurt. In contrast, a decline in agricultural output was recorded in Arapgir, Arguvan, Doğanşehir, Hekimhan, Kuluncak, Pütürge, and Yazıhan. This pattern highlights the intricate impacts of soil temperature fluctuations on apricot cultivation outcomes across the region. These findings underscore the critical need for region-specific agricultural strategies to mitigate the effects of adverse climatic conditions and optimize apricot yield.

In 2020, a detailed analysis revealed an increase in soil temperatures in the central parts of Hekimhan, while Kuluncak experienced a more widespread temperature rise. Meanwhile, Akçadağ, Yazıhan, Yeşilyurt, Battalgazi, Kale, Pütürge, Doğanyol, and Doğanşehir maintained consistent soil temperatures compared to 2019. An examination of the yield and production map for this year illustrates that districts experiencing temperature increases correspondingly showed a linear enhancement in yield and production rates. This pattern underscores the direct impact of soil temperature fluctuations on apricot agricultural productivity, emphasizing the need for adaptive management strategies in response to changing climatic conditions.

In 2021 and 2022, a nuanced examination of soil temperature variations revealed a significant change in surface thermal conditions. In 2021, temperature increases in the eastern and southeastern sectors of Arapgir were noted, with recorded temperatures ranging between 14-16 °C. Similarly, a temperature increase from the south to the central part of Arguvan was observed. Conversely, soil temperatures in the central to southern parts of Hekimhan showed a decrease. Temperatures in Kuluncak and Akçadağ averaged around 12-14 °C, while in Battalgazi, Yeşilyurt, Kale, Pütürge, and Doğanyol, they ranged between 15-17 °C. Notably, the highest production in 2021 occurred in Battalgazi with 81,988 tons, and the highest yield was recorded in Doğanyol at 74 kg per tree.

In 2022, a marked decrease in soil temperatures was observed across the southern and southwestern regions of Malatya, impacting agricultural outputs. Soil temperatures in Doğanşehir, Yeşilyurt, Battalgazi, Kale, Pütürge, and Doğanyol fluctuated between 8 and 12 °C. A gradual temperature decrease from east to west was evident in Akçadağ, with temperatures ranging between 11-13 °C. Darende exhibited a temperature decrease from central parts at 12-13 °C to 8-11 °C in peripheral areas. In contrast, Hekimhan experienced a temperature increase from northwest to southeast, with values between 13-14 °C. The highest yield in 2022 was achieved in Doğanyol at 98 kg per tree, while the lowest was in Doğanşehir at 8 kg per tree. The highest production rate was seen in Akçadağ with 49,817 tons, whereas the lowest was in Arapgir with 307 tons. As detailed in Table 3, production and yield rates across all districts between 2021 and 2022 displayed a clear correlation with the fluctuations in soil temperatures.

5. Conclusion

This longitudinal analysis meticulously investigated the impact of soil temperature on apricot productivity in Malatya, Turkey, from 2004 to 2022, revealing nuanced insights into the climatic determinants of agricultural success in the region. By employing advanced geospatial analyses and leveraging comprehensive climatic and production data, the study confirmed that soil temperature significantly influences apricot yield and production, with specific annual fluctuations closely mirroring variations in output across diverse districts.

The research demonstrated that periods of increased soil temperatures consistently correlated with heightened apricot production, particularly noted in 2016 and 2017 when some of the highest yields were recorded. For instance, in 2016, Doğanşehir and Pütürge saw a dramatic increase in yield, with temperatures notably rising to between 14-15°C, leading to yield surges up to 89 kg per tree. Conversely, 2014 was characterized by anomalously high soil temperatures which corresponded with some of the lowest yields of the decade, emphasizing the delicate balance required for optimal fruit development.

Spatial analyses further highlighted the differential impacts across the region. In 2021 and 2022, significant thermal increases in Arapgir and steady conditions in Battalgazi supported stable, high yields, contrasting with marked temperature declines in Hekimhan, where production significantly dropped. This disparity underscores the complex interplay between microclimatic conditions and apricot productivity, necessitating localized agricultural strategies. The generated maps of apricot yield and production, illustrating these dynamics, serve as crucial tools for agricultural planning. They not only enhance understanding of the temporal and spatial impacts of soil temperature but also support strategic decision-making for resource allocation, irrigation scheduling, and varietal selection adapted to climatic conditions.

Given the projected intensification of climatic extremities, further research is essential to integrate additional agronomic factors such as soil moisture levels, plantation density, and apricot varietal resistance into the model. Expanding the scope to include socio-economic analysis will also provide a fuller picture of the impacts of temperature variability on the regional agricultural economy. This study thus not only enriches the scientific literature on climate impacts on agriculture but also provides actionable insights for enhancing the resilience and sustainability of apricot production in Malatya. As the region faces ongoing and future climatic challenges, such comprehensive research will be pivotal in securing the economic viability and food security of the community.

Conflicts of Interests

Authors declare that there is no conflict of interests

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Statement contribution of the authors

This study's experimentation, analysis and writing, etc. all steps were made by the authors.

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