Heatwave Characteristics in Different Ecosystems across Türkiye: Historical and Future Insights from CMIP6 Simulations

Serhan Yeşilköy

USDA-ARS, Adaptive Cropping Systems Laboratory, Beltsville, MD, USA

Oak Ridge Institute for Education and Science, Oak Ridge, TN, USA

Istanbul Provincial of Agriculture and Forestry, Turkish Ministry of Agriculture and Forestry, Istanbul, Türkiye

Corresponding author: S. Yeşilköy (serhan-yesilkoy@uiowa.edu)

Abstract

Heatwaves pose significant threats to diverse sectors, including agriculture and forestry. This extreme weather event is characterized by prolonged periods of exceptionally high air temperatures and has caused substantial economic damage and affecting millions. During heatwave events, agricultural and forest lands are affected by intensified thermal stress and water scarcity, impacting plant health, productivity, and ecosystem stability. This study revealed the projected heatwave changes in frequency and duration over agricultural and forest areas in Türkiye based on the ensemble mean of 23 general circulation models through the two latest CMIP6 climate change scenarios (SSP3-7.0 and SSP5-8.5). Agricultural and forest lands are projected to experience dramatic increases in summer heatwave events and prolonged durations throughout two long-term periods (2041-2070 and 2071-2100) during 21st century, particularly between 36°N and 38°N latitudes. Trend analysis using the triple-ITA method confirms unstable positive trends in historical heatwave metrics over these ecosystems, transitioning to stable positive trends in future projections. These findings emphasize the escalating risk of extreme heat events for critical ecosystems in Türkiye.

Keywords: Extreme Events, Heat Stress, Agriculture, Forest, CMIP6.

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1. Introduction

The occurrence and persistence of heatwaves are due to the behavior of Rossby waves, large-scale meanders in the upper-level atmospheric jet stream. Amplified and quasi-stationary Rossby wave patterns can lead to prolonged periods of high-pressure systems remaining over a region, inhibiting the movement of weather systems and resulting in heatwave development (Domeisen et al., 2023; McGregor, 2024). Studies have shown that specific Rossby wave configurations can contribute to the intensity, duration, and spatial extent of heatwave events across mid-latitudes (Kornhuber et al., 2020). Heatwaves are defined as highly destructive natural phenomena and characterized by exceptionally high temperatures persisting longer than three consecutive days, significantly affecting agriculture (Li et al., 2024), forests (Salomón et al., 2022), public health (Campbell et al., 2018), water resources (Bakanoğulları and Yeşilköy, 2014), water ecosystems (Baydaroğlu, 2025), and the aviation sector (Burbidge et al., 2024). The Intergovernmental Panel on Climate Change's (IPCC) 6th Assessment Report (AR6) indicated that human-induced climate change is leading to more frequent extreme weather events such as heatwaves (Tripathy et al., 2023). According to the International Disaster Database (EM-DAT) database (https://public.emdat.be/data), more than 33 million people have been affected by heatwaves, and total damage has been calculated at more than 22 billion US dollars around the world since 2000. The recent ECMWF report (2024) highlighted that global air temperature in the year 2024 has increased 1.5°C over pre-industrial levels. According to the World Meteorological Organization (https://library.wmo.int/records/item/69473-european-state-of-the-climate), eastern Europe, including Türkiye, has experienced record-high numbers of strong heat stress days and tropical nights (also 2.5°C increase in air temperature). Climate change exacerbates both the frequency and projection area of land heatwaves on a global scale (Zhang et al., 2025). In addition, climate change projections indicate an increasing frequency and intensity of heatwaves throughout the 21st century (Yeşilköy and Şaylan, 2022; Wei et al., 2024).

Heatwaves impose significant and harmful consequences on the agricultural sector. Heat stress reduces crop yields (Brás et al., 2021) at critical phenological stages (Bakanoğulları et al., 2022; Yeşilköy and Demir, 2024), adversely affecting processes such as photosynthesis, pollination, and grain filling (Ping et al., 2023). Prolonged durations of extreme heat accelerate evapotranspiration (Zhao et al., 2022), increase water requirements for irrigation, and may result in water scarcity (Yeşilköy et al., 2024), especially in arid or semi-arid regions (Belleza et al., 2023). Livestock is significantly susceptible to heat stress, resulting in diminished productivity in milk and meat output, reduced fertility, and increased susceptibility to diseases (Thornton et al., 2021). Moreover, heatwaves may shift the timing and severity of pest and disease outbreaks, creating additional challenges to the management of plants and animal health (Anyamba et al., 2014). Extreme heat also plays an important role in the quality of agricultural products, influencing parameters such as fruit size, sugar content, and general marketability (Moretti et al., 2010). Soil health may deteriorate, as elevated temperatures diminish soil moisture retention and microbial activity (Allen et al., 2011). All these consequences of heatwaves for the agricultural community can be significant, including loss of income, rising costs of production, and potential food shortages.

Heatwaves present a considerable risk to forest ecosystems. Prolonged durations of excessive heat can cause vital physiological stress in trees, impairing their ability to defend against pests and diseases (Teshome et al., 2020). High temperatures can interfere with photosynthesis, diminish tree growth rates (Adams et al., 2009), and potentially result in extensive tree mortality, especially in susceptible species in arid conditions (Marchin et al., 2022). Moreover, heatwaves significantly exacerbate the likelihood and severity of wildfires (Richardson et al., 2022). Dry vegetation, combined with high temperatures and strong winds, establishes optimal conditions for ignition and rapid propagation of wildfires (Liu et al., 2014; Duane et al., 2021), leading to substantial forest devastation, biodiversity and wildlife loss, and considerable carbon emissions (Loehman et al., 2014). Heatwave-induced alterations in fire regimes might fundamentally transform forest composition and structure (Harvey and Enright, 2022), promoting fire-tolerant species and potentially resulting in persistent ecological changes (Rogers et al., 2020). Moreover, heat stress can adversely affect forest regeneration by diminishing seed viability and seedling survival rates (Kijowska-Oberc et al., 2021). Fire-induced alterations in forest health and composition resulting from heatwaves can also exert cascade impacts on associated wildlife populations (Cours et al., 2023), as well as hydrological and carbon fluxes (Yeşilköy et al., 2017; Frank et al., 2018).

There are some studies about heatwave characteristics in Türkiye. Dönmez et al. (2024) explored the future changes of humid heat in urban areas under the high-emission greenhouse gas (GHG) scenario (e.g., RCP 8.5). Arslan et al. (2024) revealed that summer heatwaves were responsible for forest fires in 2021. Erlat et al. (2021) investigated the change in extreme heat (e.g., Tx90) from 1950 to 2018 based on meteorological stations and found that Türkiye experienced more frequent and longer heatwaves after the 2000s. Can et al. (2019) analyzed the relationships between excess mortality and heatwaves from 2013 to 2017 in the megacity of Istanbul. In existing research, there is not much information about how often and how long heatwaves are expected to change on agricultural and forest lands in Türkiye according to different climate models under two CMIP6 (Coupled Model Intercomparison Project Phase 6) scenarios (SSP3-7.0 and SSP5-8.5). This study aims to address this knowledge gap by answering the following research questions.

1. What are the projected changes in heatwaves over agricultural and forest lands in Türkiye in the 21st century?

2. What are the zonal, monthly frequency, and duration changes of heatwaves?
3. Is there a trend in heatwave frequency and duration under SSP3-7.0 and SSP5-8.5 scenarios?

This paper is structured as follows: Section 2 provides a detailed description of the study area, data source, heatwave definition, and analysis performed. The spatiotemporal characteristics, trends, and monthly changes in heatwave frequency and duration over agricultural and forest lands can be found in Section 3. Within Section 4, the results were compared to the other related studies and emphasize the importance of heatwaves over agricultural and forest lands in a changing climate.

2. Materials and Methods

2.1 Study Area

The study area covers the agricultural and forest lands across Türkiye (26-56°E longitude; 36-45°N latitude). Türkiye is located in the Mediterranean Basin and considered a hotspot of climate change (Cos et al., 2022). According to the CORINE Land Cover (CLC) 2018 map, agricultural and forest land constitute 43.7 and 14.9 percent (the total is 58.6%) of the total area, respectively. Türkiye is vulnerable to drought (Türkeş, 2020) and has experienced more heatwaves and drought conditions in recent years (Serkendiz et al., 2024).

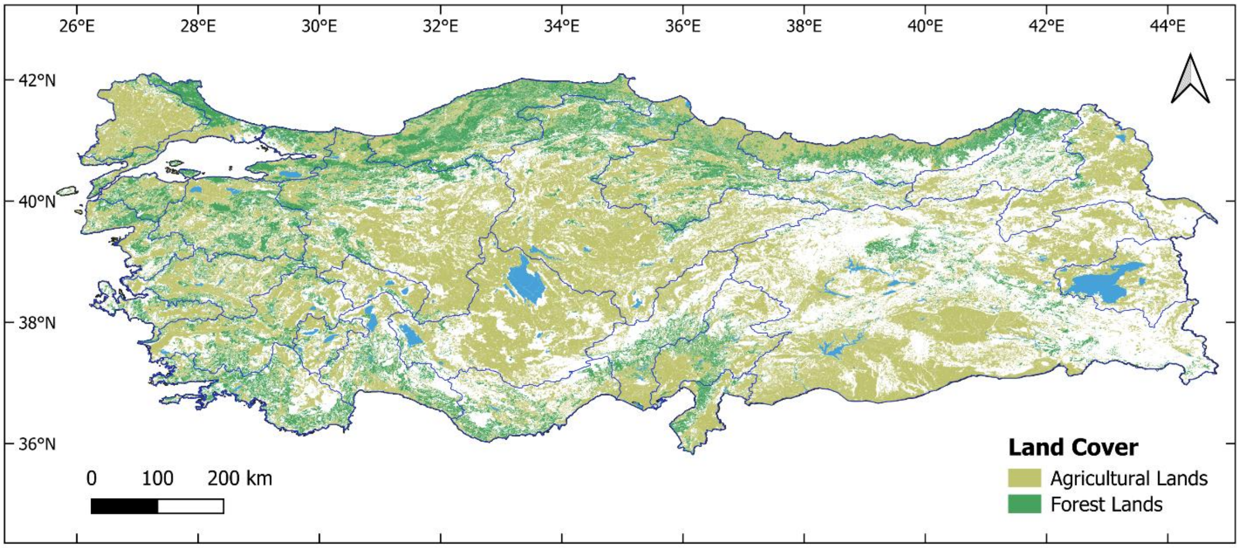

Figure 1. Yellow and green pixels represent agricultural and forest lands in Türkiye, respectively (CORINE, 2018). Blue lines represent the watershed boundaries.

2.2 Data

Gridded daily bias-adjusted maximum air temperature (T_{max}, °C) was obtained from the latest version of the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6; Thrasher et al., 2022) with 0.25-degree (~25x25 km) spatial resolution between 1985 and 2014 for the historical period. In addition, the daily projected T_{max} data from 2015 to 2100 years under two GHG emission scenarios (SSP3-7.0 and SSP5-8.5) published in the AR6 were obtained. Bias correction is an inevitable part of the climate change impact studies to reduce the uncertainty (Teutschbein and Seibert, 2012) of the projected datasets of 23 general circulation models (GCMs). The list of the GCMs dataset can be found in Table 1. The number of monthly heatwaves counts and durations were calculated for obtained GCMs of each grid cell. The uncertainty in climate variable projections can be reduced by employing the mean time series generated from a multi-model ensemble of better-performing GCMs. In this study, simple-mean-based (SM) multi-model ensemble (MME) was calculated for each grid cell (Ahmed et al., 2019).

Table 1. The List of the GCM Dataset

Driving GCM	Institute	Country
ACCESS-CM2	The Commonwealth Scientific and Industrial Research Organisation (CSIRO)	Australia
ACCESS-ESM1-5		
CanESM5	Canadian Centre for Climate Modelling and Analysis, Environment and Climate Change Canada	Canada
CMCC-ESM2	Euro-Mediterranean Center on Climate Change	Italy
CNRM-CM6-1	National Center for Meteorological Research	France
CNRM-ESM2-1		
EC-Earth3	EC-Earth Consortium	Europe
EC-Earth3-Veg-LR		
FGOALS-g3	Chinese Academy of Sciences, The Institute of Atmospheric Physics	China
GFDL-ESM4	NOAA-Geophysical Fluid Dynamics Laboratory	USA
GISS-E2-1-G	NASA Goddard Institute for Space Studies (GISS)	USA
INM-CM5-0	Institute for Numerical Mathematics (INM)	Russia
IPSL-CM6A-LR	Institute Pierre Simon Laplace (IPSL)	France
KACE-1-0-G	National Institute of Meteorological Sciences (NIMS), the Korea Meteorological Administration (KMA)	South Korea
MIROC6	Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Atmosphere and Ocean Research Institute (AORI), The University of Tokyo, National Institute for Environmental Studies (NIES), RIKEN Center for Computational Science (MIROC)	Japan
MIROC-ES2L		
MPI-ESM1-2-HR	Max Planck Institute for Meteorology	Germany
MPI-ESM1-2-LR		
MRI-ESM2-0	Meteorological Research Institute (MRI), Japan Meteorological Agency (JMA)	Japan
NorESM2-LM	NorESM Climate Modeling Consortium	Norway
NorESM2-MM		
TaiESM1	Research Center for Environmental Changes (RCEC) of Academia Sinica	Taiwan
UKESM1-0-LL	Met Office Hadley Centre (MOHC), the Natural Environment Research Council (NERC)	UK

2.3 Heatwaves Definition

A heatwave event occurs when T_{max} exceeds the 90th percentile-based thresholds for at least 3 consecutive days for each grid cell, where the 90th percentile is based on 30-year (1985-2014) long term period (Perkins-Kirkpatrick and Gibson, 2017). This threshold was calculated based on the daily T_{max} data from 1985-2014 period. Heatwave duration was calculated as the number of days from the beginning to the end of a heatwave event (Perkins-Kirkpatrick and Lewis, 2020). After calculating the number of heatwaves and their durations for each grid, monthly total amounts were calculated for agricultural and forest areas. Heatwave count and duration are useful in understanding heatwave interactions with yield reduction (Riedesel et al., 2024) and wildfire (Sharples et al., 2021).

2.4 Trends of Heatwave Events and Durations

To capture trends in heatwave events and durations, the Innovative Trend Analysis (ITA) approach, developed by Şen (2012), together with the Triple ITA (T-ITA), was presented and assessed for stability for time series data (Güçlü, 2018) for improved trend detection. The T-ITA approach offers a visual illustration of time series data, divided chronologically into four parts. The subseries are subsequently ordered in either an ascending or decreasing order. A scatter diagram can be generated by comparing the first part with the second, the second part with the third, and the third part with the fourth part. If scatter points are positioned above (or below) the trendless (1:1) line, a strong increasing (or declining) trend is indicated.

3. Results and Discussions

Figures 2 and 3 illustrate the spatial distribution of the number of heatwave events and durations across Türkiye for each month of the year from 1985 to 2014. This analysis highlights the significant seasonal and spatial variability of heatwave occurrences in Türkiye between 1985 and 2014. The long-term monthly mean heatwave events were extracted by using a spatially weighted mean due to the shape of the earth (Yeşilköy and Demir, 2024). Monthly means of heatwaves between 1985 and 2014 were calculated as 3.66 events in winter, 3.70 events in spring, 3.80 events in summer, and 3.78 events in autumn. The bar chart (Fig. 2 right) compares heatwave counts across seasons (winter, spring, summer, and autumn) for three periods: 1985-1994, 1995-2004, and 2005-2014. The mean number of heatwaves between 1995 and 2014 was calculated as 4.33 events/season and is 0.61 events/season more than the mean in other decades (3.72 events/season). During this period (1995-2004), prolonged droughts and extreme heat occurred throughout Türkiye.

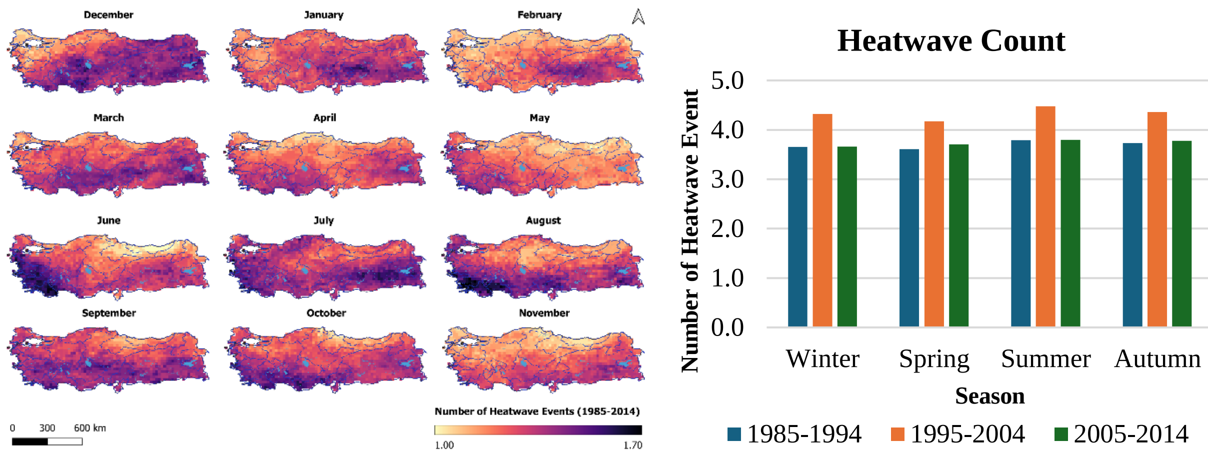

Figure 2. Spatial characteristics of monthly mean of heatwave counts during the 1985-2014 period (left) and mean seasonal count of different periods (1985-1994, 1995-2004, and 2005-2014) (right).

The summer months, which exhibited the highest number of heatwave events, also correspond with longer mean heatwave durations, especially in the western and southeastern regions, where durations often exceed 4 days. Spring and autumn generally show lower heatwave frequencies, and when events do occur, their duration is also typically shorter, predominantly around 3 days across most of the country. This integrated perspective on both the frequency and persistence of heatwaves provides a more comprehensive understanding of the spatiotemporal characteristics of extreme heat events in Türkiye. The mean heatwave duration during seasons was calculated for three consecutive decades (1985-1994, 1995-2004, and 2005-2014). The highest heatwave durations were found during the 1995-2004 period and calculated as 9.97 days/season. The mean durations of heatwaves in other decades were calculated as 9.49 and 9.50 days/season during 1985-1994 and 2005-2014, respectively.

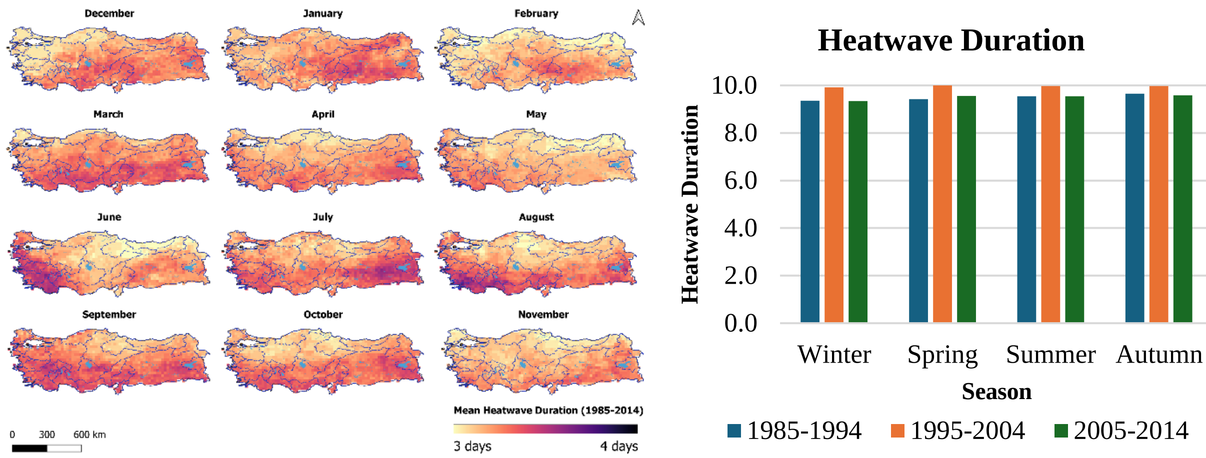

Figure 3. Spatial characteristics of the monthly mean of heatwave durations during the 1985-2014 period (left) and the mean seasonal count of different periods (1985-1994, 1995-2004, and 2005-2014) (right).

Figure 4 illustrates the zonal mean of monthly heatwave count (left) and duration (right), revealing a clear latitudinal dependence and a projected intensification of heatwave characteristics in the 21st century (between 2015 and 2100) under different GHG (SSP3-7.0 and SSP5-8.5) scenarios. Historically (1985-2014), the frequency of monthly heatwave events showed relatively low variation with latitude; the mean and standard deviation were calculated as 1.25±0.08 across the approximately 36°N to 42°N range, while the mean heatwave duration remained short, typically below 4 days. The highest emissions scenario (SSP5-8.5) consistently projects a higher number of monthly heatwave events and longer heatwave durations across most latitudes compared to the SSP3-7.0 scenario, highlighting the impact of emissions pathways on future heatwave count and duration. Future projections (2015-2100) under both SSP3-7.0 and SSP5-8.5 scenarios indicate a substantial increase of 6.1 and 7.7 days in the frequency and 5.9 and 8.6 days in the duration of monthly heatwave events. The increase in frequency and duration is particularly higher within the 36°N to 38°N latitudes. The increased number of heatwave events and duration in this latitudinal zone were calculated as 8.6 and 10.4 events/year and 10.9 and 14.2 days/year for SSP3-7.0 and SSP5-8.5 scenarios, respectively.

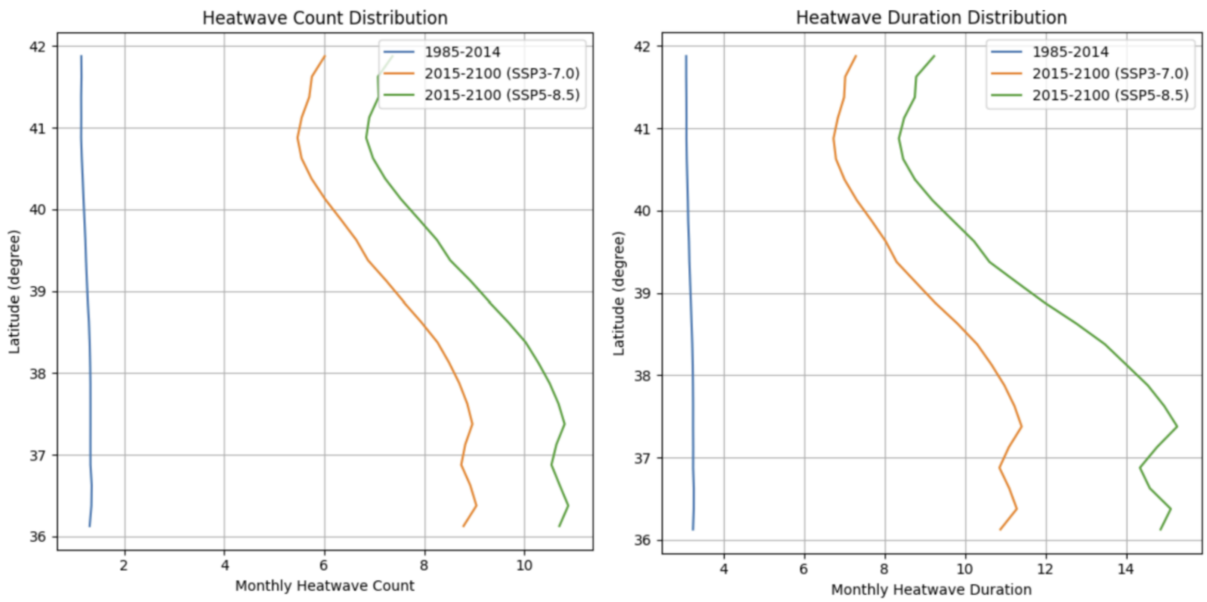

Figure 4 (left). Zonal mean of number of heatwave events and (right) duration.

The simultaneous occurrence of increased frequency and extended length of heatwaves in these regions during summer, along with projected scenarios, intensifies the cumulative heat exposure risk for agricultural and forest lands. Figures 5 and 6 depict the monthly occurrences and durations of heatwave events under historical conditions and two predicted climatic scenarios for the periods 2041-2071 and 2071-2100 throughout agricultural regions in Türkiye. Under the SSP3-7.0 scenario (Fig. 5 left), predictions for the mid-21st century (2041-2070) forecast an escalation of heatwave episodes from 4.0 to 22.0, especially during the summer months. Climate projections for the late 21st century (2071-2100) under SSP3-7.0 indicate a significant increase in summer heatwave frequency, increasing from 4.0 to 43.4 occurrences with high intensity. The SSP5-8.5 scenario (Fig. 5, right) forecasts a more pronounced rise in heatwave occurrences relative to SSP3-7.0. By the mid-21st century (2041-2070), the incidence of summer heatwaves is markedly elevated (28.1 occurrences) compared to the historical period, and the duration of the heatwave season dramatically increases. In the late 21st century (2071-2100), under SSP5-8.5, there is a significant rise, quantified at 54.9 events, in the frequency of monthly heatwave occurrences throughout the summer. All months exhibit a significant rise in the frequency and duration of heatwaves throughout agricultural lands under both climate scenarios.

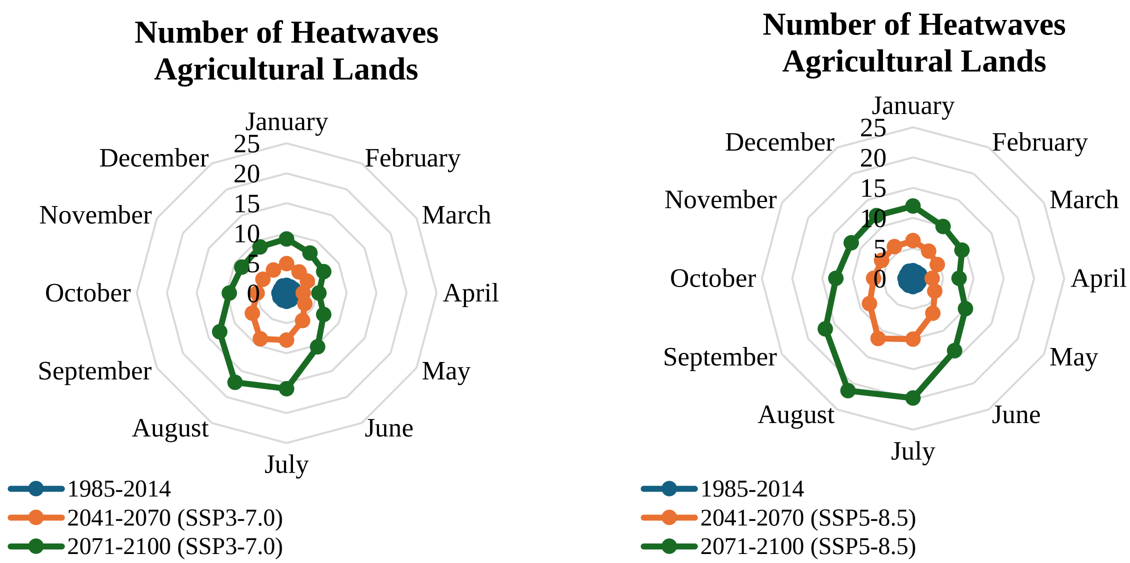

Figure 5. Number of monthly heatwave events under SSP3-7.0 (left) and SSP5-8.5 (right) over agricultural lands in Türkiye.

Figure 5 reveals a strong seasonal pattern in heatwave duration over agricultural lands. Historically, heatwaves exhibit the longest durations during the summer months, with mean durations of 9.7 days. It was quantified that the heatwave durations were prolonged in both climate scenarios and in future periods. The SSP3-7.0 climate scenario was calculated as 24.3 and 49.3 days in the summer months of the 2041-2070 and 2071-2100 periods, respectively. In the SSP5-8.5 scenario during both periods, it increased to dramatic values and was calculated as 30.5 and 71.6 days, respectively. In the SSP5-8.5 scenario, the entire months of August and September in the 2071-2100 period are spent with heatwaves.

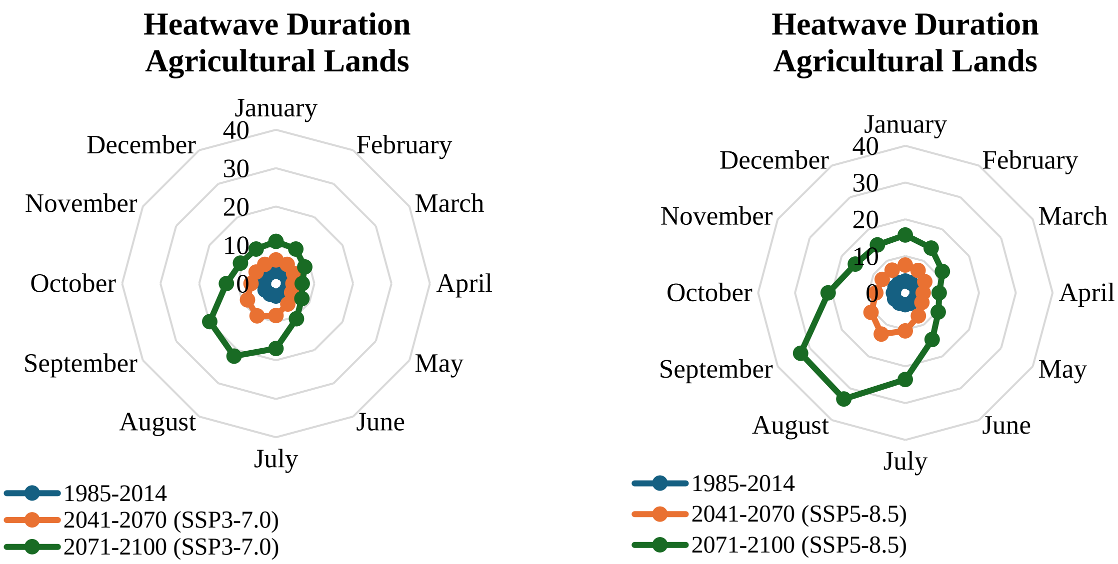

Figure 6. Monthly heatwave durations under SSP3-7.0 (left) and SSP5-8.5 (right) over agricultural lands in Türkiye.

Figures 7 and 8 illustrate the monthly heatwave events and duration of historical and under two projected climate scenarios and periods (2041-2071 and 2071-2100) over forest lands in Türkiye. Forest areas have experienced significant increases in heatwave events and durations across all months and climate scenarios. The highest increase occurs in the summer months, as in agricultural lands. The increase in heatwave events is considerably higher in the late 21st century than in the mid-21st century and is calculated as 9.2 and 6.0 on average in the SSP3-7.0 scenario and 12.2 and 9.2 in the SSP5-8.5 scenario, respectively. As seen from Figure 7, it was determined that the highest increase in heatwave numbers will occur in the summer months. Changes in extreme heat events were calculated as 27.1 and 41.9 days in the 2041-2070 and 2071-2100 periods based on the SSP3-7.0 scenario and 41.9 and 53.3 days based on the SSP5-8.5 scenario, respectively.

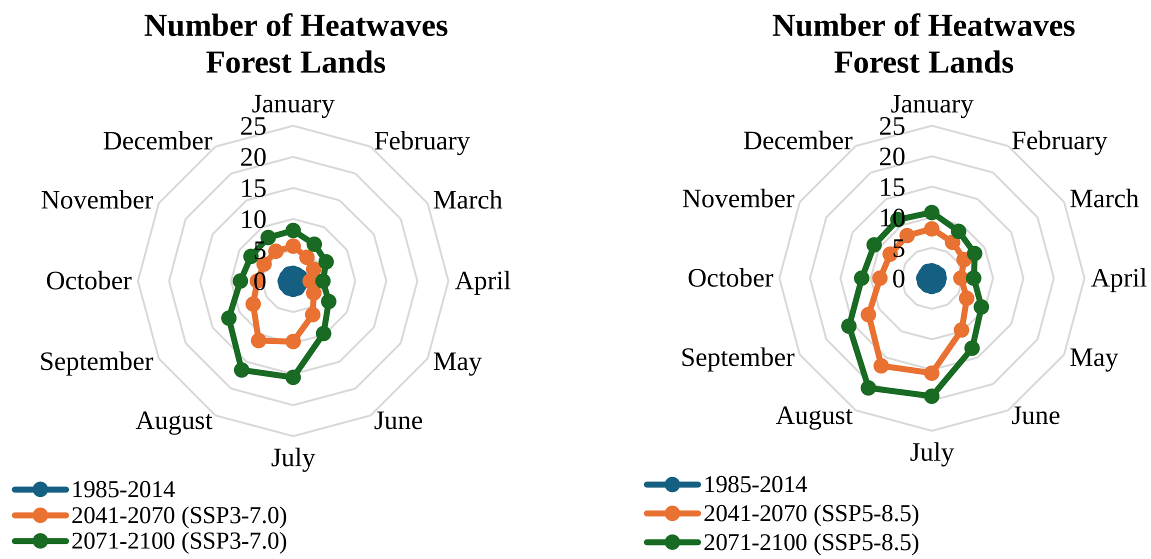

Figure 7. Number of monthly heatwave events under SSP3-7.0 (left) and SSP5-8.5 (right) over forest lands in Türkiye.

The increase in the duration of heatwaves in forest lands increased to monthly averages of 6.0 and 11.2 days in the SSP3-7.0 scenario in the 2041-2070 and 2071-2100 periods and to monthly averages of 7.3 and 16.3 days in the SSP5-8.5 scenario, respectively. The season in which the heatwave duration increases the most is determined as summer and was calculated as 23.7 and 47.5 days and 29.6 and 68.4 days during 2041-2070 and 2071-2100 based on more realistic and high GHG emission scenarios, respectively. On the other hand, the two months in which it increases the most are August (21.2 and 30.9 days) and September (18.3 and 30.2 days) in the late 21st century. In the mid-21st century, it was determined that heatwave durations increased the most in August (9.6 and 12.6 days) and July (8.2 and 10.1 days).

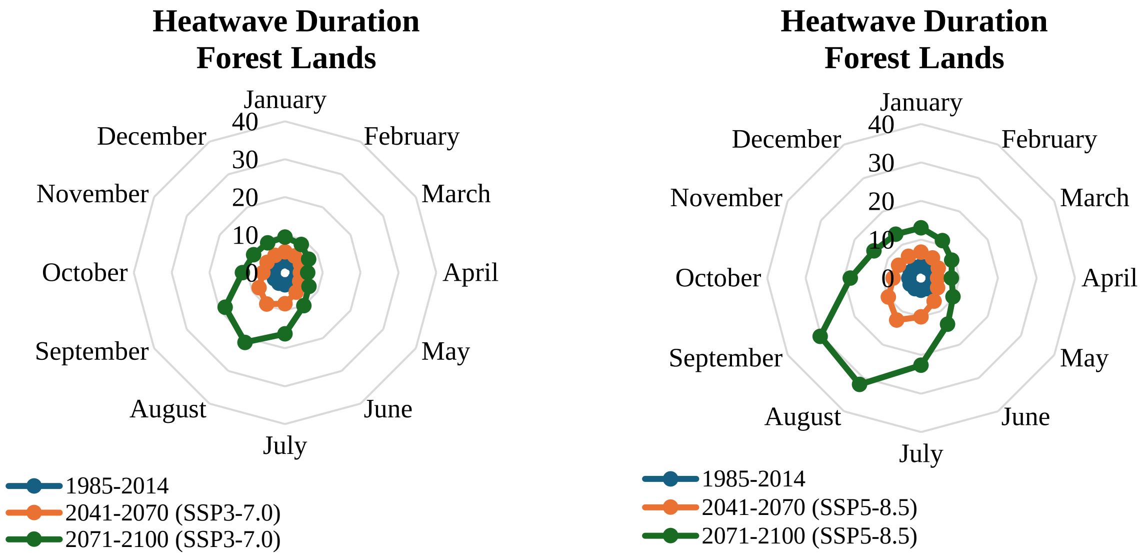

Figure 8. Monthly heatwave durations under SSP3-7.0 (left) and SSP5-8.5 (right) over forest lands in Türkiye.

In Fig. 9-12 illustrate the trends in heatwave events and durations over agricultural and forest lands during the historical and projected period under two climate scenarios based on the triple-ITA method. In Figure 9, the total number of monthly heatwave events during the historical period (1985-2014) shows an unstable monotonic positive trend. Monthly heatwave events over agricultural lands for the 21st century, based on two projected scenarios, have stable monotonic positive trends.

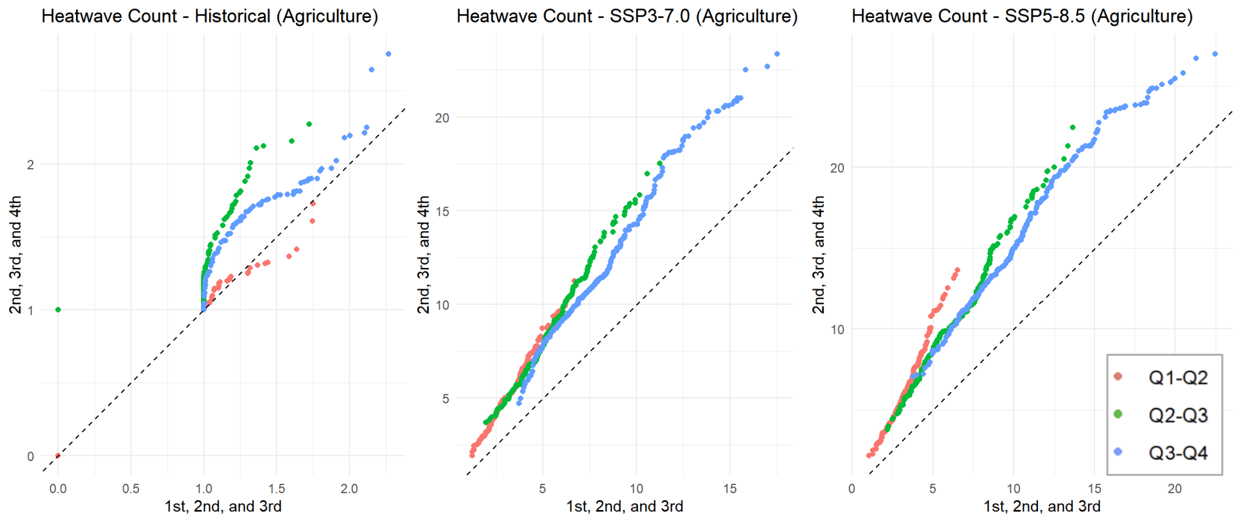

Figure 9. Triple ITA results of number of monthly heatwave events over agricultural lands during historical (left) and projected periods under SSP3-7.0 (middle) and SSP5-8.5 (right) scenarios.

In Figure 10, the total number of monthly heatwave events over forest lands during the historical period shows an unstable monotonic positive trend (Fig. 10 left). Monthly heatwave events under two projected scenarios have stable monotonic positive trends (Fig. 10 middle, right).

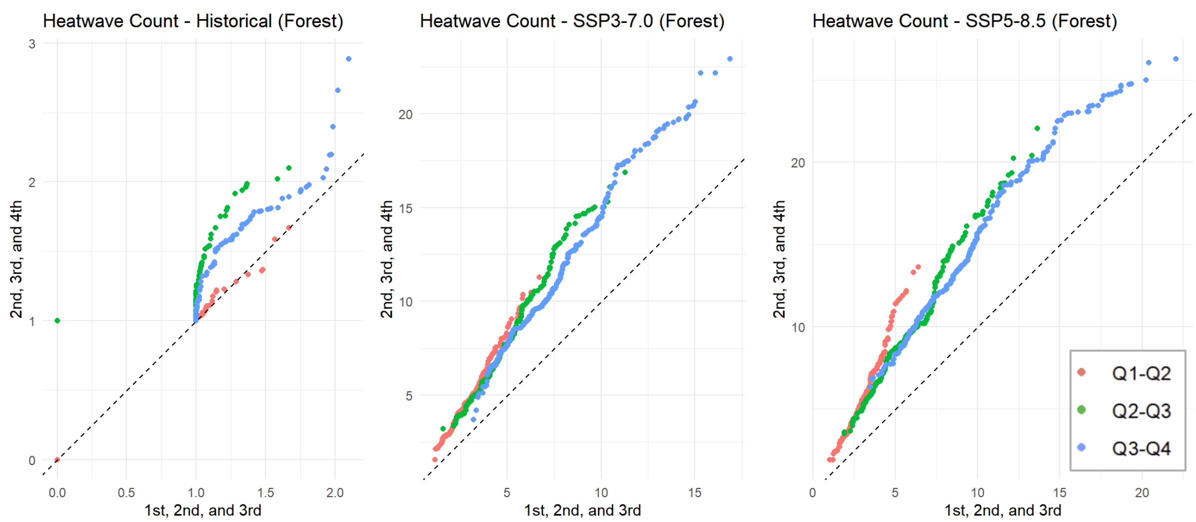

Figure 10. Triple ITA results of number of monthly heatwave events over forest lands during historical (left) and projected periods under SSP3-7.0 (middle) and SSP5-8.5 (right) scenarios.

In Figs. 11 and 12, heatwave durations over agricultural and forest lands have an unstable monotonic positive trend during the historical period (1985-2014). Heatwave durations under both climate projections over agricultural and forest lands have stable monotonic positive trends from 2015 to 2100 years.

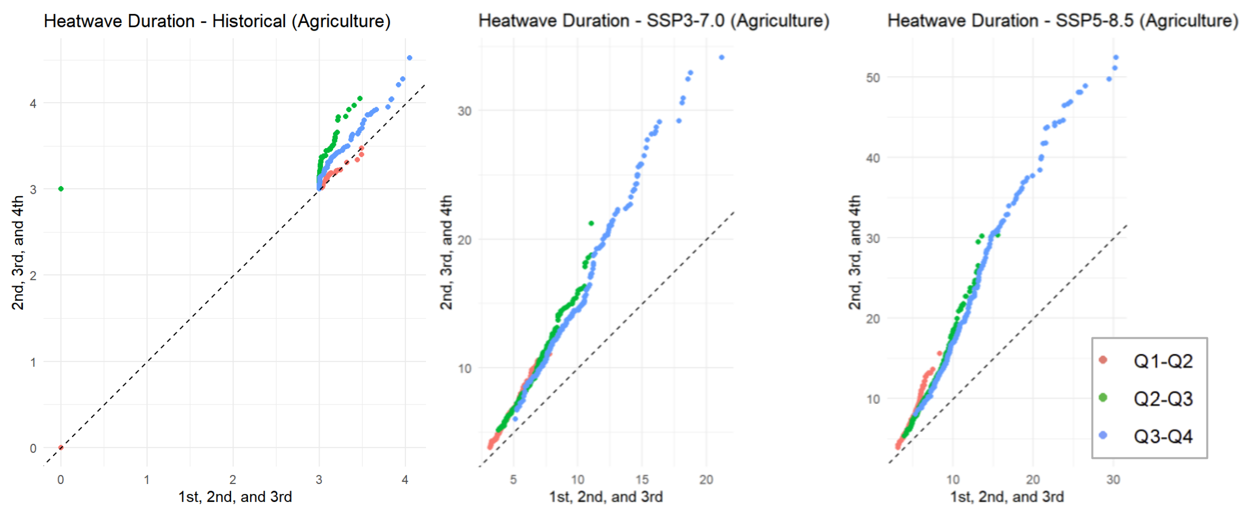

Figure 11. Triple ITA results of heatwave duration over agricultural lands during historical (left) and projected periods under SSP3-7.0 (middle) and SSP5-8.5 (right) scenarios.

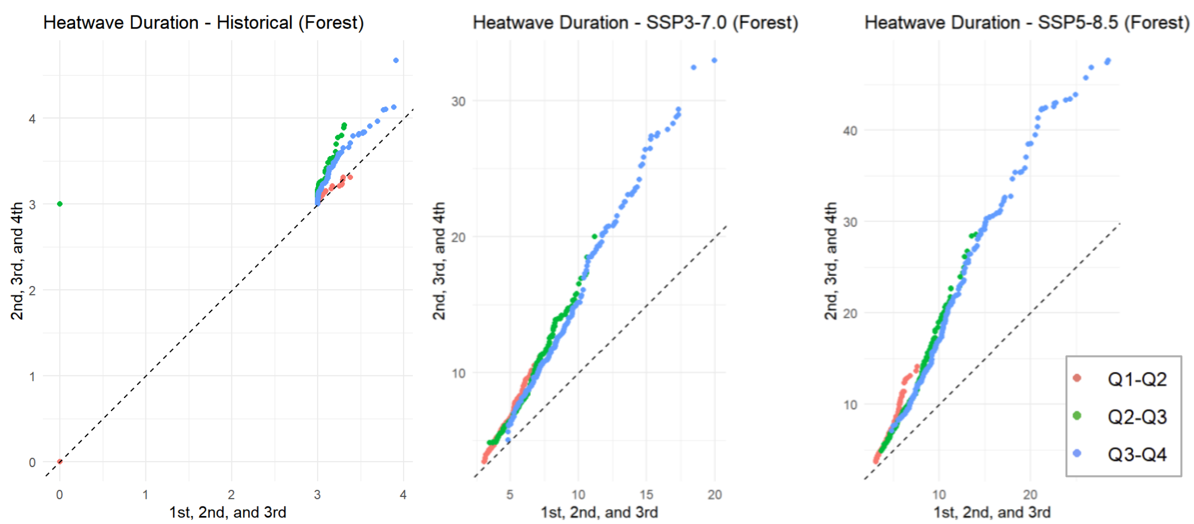

Figure 12. Triple ITA results of heatwave duration over forest lands during historical (left) and projected periods under SSP3-7.0 (middle) and SSP5-8.5 (right) scenarios.

4. Conclusion

Heatwaves are considered one of the most important extreme climate events and have adverse impacts on the public and ecosystems. Heatwave events and durations were detected based on the 90th percentile-based threshold for each grid cell during three long-term periods (1985-2014, 2041-2070, and 2071-2100) using the bias-adjusted multi-model ensemble mean of 23 CMIP6 simulations over agricultural and forest lands in Türkiye. The results revealed that the number of monthly heatwave events and durations increased under SSP3-7.0 and SSP5-8.5 climate scenarios. In agricultural lands, monthly heatwave events and durations are expected to increase 7.2 and 8.8 events per year and 8.9 and 11.4 days per year under SSP3-7.0 and SSP5-8.5, respectively. In forest areas, monthly heatwave events and durations are expected to increase 6.7 and 8.2 events per year and 8.2 and 10.5 days per year under SSP3-7.0 and SSP5-8.5, respectively. Future climate projections under both the SSP3-7.0 and SSP5-8.5 scenarios indicate a substantial intensification of heatwave characteristics throughout the 21st century (2015-2100). There is a noticeable pattern based on latitude, with predictions showing a big rise in how often heatwaves happen (6.1 and 7.7 days each month) and how long they last (5.9 and 8.6 days each month), especially in the area between 36°N and 38°N. Trend analysis using the triple-ITA method further supports these findings, revealing unstable monotonic positive trends in historical heatwave events and durations over both agricultural and forest lands. Notably, future projections under both climate scenarios show stable monotonic positive trends for both heatwave frequency and duration throughout the 21st century in these critical land-use areas. These projected increases in the frequency and duration of heatwaves pose a significant threat, intensifying cumulative heat exposure risks for both agricultural and forest ecosystems across Türkiye.

Especially in summer, heatwave events and durations were predicted to increase dramatically in both land covers. Monthly mean events were calculated as 9.7 and 11.8 in agricultural lands and 9.5 and 11.5 in forest areas under SSP3-7.0 and SSP5-8.5, respectively. In terms of heatwave duration in summer, monthly means were expected to increase to 11.0 and 14.4 days in agricultural lands and 10.7 and 13.9 in forest areas under both climate scenarios. The increase in the number and duration of heatwaves causes yield reductions (Lesk et al., 2016), impaired product quality (Parker et al., 2020), deterioration of soil health (Abdelhak, 2022), decreased livestock productivity (Vroege et al., 2023), increased water demand for irrigation (Zaveri and Lobell, 2019) in agriculture, biodiversity loss (Rovira et al., 2024), enhanced risk and severity of wildfires (Varga et al., 2022) in forest areas, and adverse impacts on carbon and water cycles (Chen et al., 2024).

The results were compared with those of other studies in the literature. Gumus et al. (2023) expected an increase in extreme maximum air temperature of 5.1°C over Türkiye under the SSP5-8.5 scenario. Almazroui et al. (2021) investigated the global maximum air temperature trends and found that the number of heatwaves is expected to more than double compared to the historical period. A study by Ruosteenoja and Jylhä (2023) analyzed the projected heatwaves in Europe under 0.5-2°C increases in warming levels and revealed that the mean annual count of heatwave days is projected to be more than sixfold in southern Europe, including Türkiye. Chervenkov and Slavov (2025) performed a multi-model ensemble of GCMs CMIP6 data to investigate the projected heating index. Their results indicated that some part of Türkiye was the only region where there was a statistically significant positive trend in heat index under the SSP3-7.0 scenario, and the trend magnitude intensified under SSP5-8.5 as expected. The increasing frequency and duration of heatwaves exert profound and detrimental effects on forest ecosystems through a variety of interconnected mechanisms, impacting their health, composition, and overall resilience. Based on the findings of this study, mitigating the impacts of increasing heatwave frequency and duration on agricultural and forest lands necessitates a multi-faceted approach encompassing both proactive and reactive strategies.

- Implement water-efficient irrigation techniques: To mitigate the impacts of prolonged heatwaves, promote the adoption of advanced irrigation systems such as drip irrigation and micro-sprinklers to optimize water usage and reduce evaporative losses.

- Develop and promote heat-tolerant crop varieties: Invest in research and breeding programs focused on developing and disseminating crop cultivars that exhibit enhanced tolerance to high temperatures and water stress, ensuring agricultural productivity under projected climate conditions.
- Adopt sustainable land management practices: Encourage practices such as conservation tillage, crop rotation, and the use of cover crops to improve soil health, enhance water retention.
- Enhance forest monitoring and early detection systems: Strengthen surveillance systems for early detection of heat-induced stress, increased fire risk, and pest outbreaks in forest ecosystems.
- Implement adaptive forest management strategies: Adopt management practices that promote forest resilience, such as thinning to reduce competition for water and nutrients, and favoring the regeneration of native, drought-tolerant tree species.

Credit Authorship Contribution Statement

Serhan Yeşilköy: Conceptualization; Methodology; Data Processing; Analysis; Writing – Original Draft.

Declaration of Competing Interest

The author declares that I have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

This study used daily bias-adjusted data, which is available at https://www.nccs.nasa.gov/services/data-collections/land-based-products/nex-gddp (Last accessed on 25.03.2025). CORINE 2018 map can be found at https://doi.org/10.2909/960998c1-1870-4e82-8051-6485205ebbac (Last accessed on 25.03.2025)

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