

Research Article

Climate Change In Türkiye: Evidence From A Structural Break Analysis

Türkiye’de İklim Değişikliği: Yapısal Kırılma Analizinden Kanıtlar

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Abstract

Since the second half of the 20th century, scientific evidence has firmly established climate change as an irreversible and serious global issue, leading to a steady increase in the number of studies addressing the topic. Temperature and precipitation are two primary indicators of climate change. This study investigates the presence of climate change in Türkiye’s NUTS-2 regions by examining long-term trends in these two variables. Data covering the period from 1950 to 2021 were obtained from the station-based records of the Turkish State Meteorological Service. The datasets were aggregated by NUTS-2 regions, and the Bai-Perron multiple structural break analysis was applied to identify significant shifts in temperature and precipitation patterns. The analysis detected structural breakpoints in average temperature across 25 out of 26 regions, with the exception of the TRA1 region (which includes Erzurum, Erzincan, and Bayburt provinces). These breakpoints primarily occurred during the 1990s and early 2000s. Across all regions, temperatures exhibited varying degrees of increase. The most significant temperature rise was observed in the TRB2 region (Van, Muş, Bitlis, and Hakkari), while the smallest increase occurred in the TR81 region (Zonguldak, Karabük, and Bartın). No structural breakpoints were identified in precipitation levels, suggesting that the pronounced changes in temperature have not yet been mirrored in precipitation patterns. However, when precipitation trends were analyzed relative to the years in which temperature breakpoints occurred, notable regional variations in precipitation amounts were observed. The effects of urbanization and industrialization on temperature change were also examined. The analysis revealed a statistically significant relationship between temperature change and urbanization, but no significant relationship with industrialization.

JEL Classification: C32, Q54

Keywords: Climate Change; Structural Break; Temperature; Precipitation; Bai-Perron Test.

Öz

20. yüzyılın ikinci yarısından itibaren bilimsel kanıtlar, iklim değişikliğini geri dönüşü olmayan ve ciddi bir küresel sorun olarak kesin bir şekilde ortaya koymuş, bu da konuyla ilgili çalışmaların sayısında istikrarlı bir artışa yol açmıştır. Sıcaklık ve yağış, iklim değişikliğinin iki temel göstergesidir. Bu çalışma, Türkiye’nin NUTS-2 bölgelerinde iklim değişikliğinin varlığını, bu iki değişkende uzun vadeli eğilimleri inceleyerek araştırmaktadır. 1950-2021 dönemini kapsayan veriler, Meteoroloji Genel Müdürlüğü’nün istasyon bazlı kayıtlarından elde edilmiştir. Veriler Düzey-2 bölgeleri itibarıyla hesaplanmış ve sıcaklık ile yağış desenlerinde önemli değişimlerin

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belirlenmesi için Bai-Perron çoklu yapısal kırılma analizi uygulanmıştır. Analiz, TRA1 bölgesi (Erzurum, Erzincan ve Bayburt illerini içerir) hariç, 26 bölgeden 25'inde ortalama sıcaklıkta yapısal kırılma noktaları tespit etmiştir. Bu kırılma noktaları ağırlıklı olarak 1990'lar ve 2000'lerin başında meydana gelmiştir. Tüm bölgelerde sıcaklıklar farklı derecelerde artış göstermiştir. En belirgin sıcaklık artışı TRB2 bölgesinde (Van, Muş, Bitlis ve Hakkari) gözlenirken, en küçük artış TR81 bölgesinde (Zonguldak, Karabük ve Bartın) kaydedilmiştir. Yağış seviyelerinde yapısal kırılma noktaları tespit edilmemiş, bu da sıcaklıkta görülen belirgin değişimlerin henüz yağış desenlerinde karşılık bulmadığını göstermektedir. Ancak, yağış eğilimleri sıcaklık kırılma noktalarının meydana geldiği yıllara göre analiz edildiğinde, yağış miktarında dikkat çekici bölgesel farklılıklar gözlenmiştir. Kentleşme ve sanayileşmenin sıcaklık değişimi üzerindeki etkileri de incelenmiştir. Analiz, sıcaklık değişimi ile kentleşme arasında istatistiksel olarak anlamlı bir ilişki olduğunu ortaya koymuş, ancak sanayileşme ile anlamlı bir ilişki bulunmamıştır.

JEL Sınıflaması: C32, Q54

Anahtar Kelimeler: İklim Değişikliği; Yapısal Kırılma; Sıcaklık; Yağış; Bai-Perron Testi.

1. Introduction

The transformation of the world following the Industrial Revolution led to a dramatic increase in production and consumption, which, in turn, resulted in the more intensive and often reckless use of production inputs, particularly fossil fuels. The careless discharge of waste into the environment, combined with rapid urbanization and population growth during this period, significantly amplified the destructive impact of these developments.

In recent years, growing awareness among the global public and policymakers has driven increased research, evaluation, and analysis of the impacts of global warming and climate change. Climate change is now widely recognized as one of the most critical threats to both current living standards and the long-term future of humanity. Its consequences are evident in the increasing frequency and severity of natural disasters, shifts in agricultural patterns and yields, and changes in the availability of surface and groundwater resources. While some regions may initially experience certain positive effects from climate change, the overall global impact is considered overwhelmingly negative.

Changes in temperature and precipitation are the two primary indicators used to assess the presence of climate change. Long-term analyses of these variables can reveal whether climate change is occurring in a particular region. Structural breaks in the trends of temperature and precipitation series are interpreted as signs of climate-related changes. When such breaks are detected through econometric analysis, they may indicate the onset or intensification of climate change in the region under study.

Due to its varied geography and transitional climate zones, Türkiye is highly susceptible to the effects of climate change. Understanding regional patterns of change is crucial for developing targeted adaptation strategies. However, while national-level studies have proliferated, empirical research at the regional scale using robust econometric techniques remains limited.

This study aims to contribute to this gap by examining the presence of climate change in Türkiye's NUTS-2 regions¹ through multiple structural break analysis of temperature and precipitation trends. Using station-based data from the Turkish State Meteorological Service covering the period 1950–2021, the study identifies significant breakpoints in temperature trends across nearly all regions, with varying degrees of warming. Notably, the most pronounced temperature increases were observed in the TRB2 region (Van, Muş, Bitlis, and Hakkari), while the smallest changes occurred in the TR81 region (Zonguldak, Karabük, and Bartın). In contrast, no structural breaks were found in precipitation patterns, suggesting that temperature shifts may not yet have translated into major disruptions in precipitation at the regional level. However, region-specific changes in precipitation were observed when examined relative to the years of temperature breakpoint years. The study also investigates the relationship between temperature change, urbanization, and industrialization. The results indicate a statistically significant association between temperature change and urbanization rates, while no significant relationship was found with industrialization.

The remainder of the study is structured as follows: the next section introduces the key concepts of

¹ Nomenclature of Territorial Units for Statistics (NUTS) is the European Union Statistical Classification of Territorial Units.

climate change and global warming. This is followed by a detailed explanation of the dataset and econometric methodology employed. The study then presents the empirical findings and concludes with a discussion and evaluation.

2. Literature Review

2.1 Climate and Climate Change

Climate is defined by the averages and extremes of meteorological variables such as temperature, precipitation, wind, and atmospheric pressure (MGM, 2015). It reflects the statistical mean and variability of these variables over periods of a decade or longer. In contrast, weather refers to the atmospheric conditions observed on a specific day, month, or year (Nordhaus, 2013). The distinction between climate and weather is particularly important when evaluating their impacts, as humans, plants, and animals experience weather events (e.g., temperature fluctuations, precipitation) on a daily or seasonal basis, rather than long-term statistical averages (Rahmstorf & Schellnhuber, 2020).

Climate change—regardless of its causes—is defined as long-term alterations in the average conditions and variability of the climate over decades or more. Global climate change encompasses both natural fluctuations throughout Earth’s history and those driven by human activity (MGM, 2015). The United Nations Framework Convention on Climate Change (UNFCCC), established in 1994, defines climate change as “a change in climate which is attributed directly or indirectly to human activities that alter the composition of the global atmosphere, in addition to natural climate variability observed over comparable time periods.”

The effects of climate change are not uniform; they vary significantly depending on a region’s atmospheric and geographic characteristics. Changes in atmospheric circulation patterns can shift the trajectories of high/low pressure systems or alter prevailing wind directions. As a result, some regions may experience rising temperatures, while others may see cooling trends. Likewise, changes in precipitation patterns may include increases or decreases in overall rainfall, greater variability, and more frequent extreme events such as floods or droughts. Wind speeds and storm intensities may also rise or fall depending on the region (Rahmstorf & Schellnhuber, 2020).

Global warming², a key manifestation of climate change, has already led to an estimated temperature increase of approximately 1.2°C. Under current trajectories, projections suggest a rise of 3–4°C by the end of the 21st century. This makes it virtually certain that the regional impacts of climate change will intensify in the coming decades. Notable global consequences include glacial retreat, shrinking sea ice in polar regions, thawing permafrost, melting ice sheets in Greenland and Antarctica, rising sea levels, changes in ocean currents, and a greater frequency of extreme weather events (Rahmstorf & Schellnhuber, 2020).

Climate models are essential tools for identifying the drivers and magnitude of climate change, as well as for projecting future scenarios. Key findings from these models include the following stylized facts: (i) Current atmospheric CO₂ accumulation is significantly higher than levels observed over the past 650,000 years, (ii) Depending on the scenario, the projected global temperature increase from 1900 to 2100 ranges between 1.8 and 4.0°C, (iii) Sea level rise over the 21st century is estimated to fall between 18 and 60 centimeters, excluding the potential contributions from large ice sheet melting, (iv) Storm intensity is expected to increase, (v) Temperatures in the Arctic and over landmasses are projected to rise faster than the global average, (vi) Many regions will experience more hot days and fewer cold days. (Rahmstorf & Schellnhuber, 2020).

Climate change constitutes a severe risk to agriculture, freshwater availability, and sustainable development. Rising sea levels, desertification, and extreme weather events already affect millions of people worldwide. The Intergovernmental Panel on Climate Change³ (IPCC), in its Third Assessment

² Global warming is defined as the increase in Earth's surface temperature due to the release of gases such as methane and carbon dioxide into the atmosphere as a result of human activities and the reduction of forest cover. (Houghton, 2005)

³ Formed in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), the Intergovernmental Panel on Climate Change (IPCC) aims to equip governments globally

Report (2001), concluded that human activities are the primary driver of recent global warming. Beyond its environmental implications, climate change carries profound political, social, and economic consequences.

2.2 Structural Break Literature

Economic interdependencies are not static; they can be altered by governmental policies, advancements in technology, environmental conditions, and market forces, testing for structural change—or structural breaks—has long been a central concern in econometrics. In recent years, the importance of structural break analysis has grown due to major global incidents such as the coronavirus outbreak, the global financial crisis, supply chain disruptions.

These events are significant because structural breaks violate the assumption of stationarity, a foundational premise in time series modeling. Under the stationarity assumption, statistical properties such as the mean and variance of a time series are expected to remain constant over time. When a structural break occurs, these properties change, undermining the reliability of conventional time series models.

Initial research on structural breaks concentrated on modeling a single disruption at a specific, predetermined time point. Notably, Quandt (1958) and Chow (1960) developed tests for detecting such breaks. Over time, more sophisticated methods have emerged to allow for multiple and unknown breakpoints. A summary of key tests, their development dates, and associated studies is presented in Table 1.

Table 1: Development of the Structural Break Literature

Characteristics	Contributing Research
Single break, known date	Quandt (1958), Chow (1960)
Unit root test with the inclusion of a known date in the model	Perron (1989)
Single unknown break point in regression coefficients	Nyblom (1989); Andrews (1993), Hansen (1992)
Estimation of the number of mean changes in a sequence of variables	Yao (1988), Yin (1988), Yao and Au (1989)
Considering multiple changes in a linear model estimated by least squares and estimating the number of changes using a modified Schwarz criterion	Liu, Cizeau, Meyer, Peng, and Stanley (1997)
Estimation of multiple structural breaks in a linear model estimated by least squares	Bai and Perron (1998, 2003)
Breaks in X, trend, and coefficients	Ericsson (2011)

Source: Developed by the authors based on Ericsson, Dore, and Butt (2022).

Although there are studies in the literature that apply structural break tests to temperature and precipitation data to investigate climate change, no such research has been identified for Türkiye. This study aims to fill that gap by applying structural break tests to investigate whether structural changes in temperature occurred across Türkiye’s NUTS-2 regions during the 1950–2021 period and, if so, to identify the unknown break date(s). Given that both the number and timing of potential breaks were unknown, the Bai-Perron multiple structural break test was employed. This method allows for the detection of multiple breakpoints at unknown dates within a time series.

The model used for the Bai-Perron test, which accounts for m structural breaks at unknown points in time, is presented below.

2.3 Bai-Perron Test

The method developed by Bai and Perron (1998, 2003) is designed to detect multiple structural breaks

with scientific insights for crafting climate policies. Its reports are crucial for international climate change discussions. The IPCC is made up of 195 member states from either the United Nations or the WMO.

by identifying unknown break dates within a linear regression model estimated using the least squares method.

The model used in the Bai-Perron test, which allows for m structural breaks at unknown moments in time, is presented below.

$$\begin{aligned}
 Y_t &= x'_t\beta + z'_t\delta_1 + u_t & t = 1, 2, \dots, T_1 \\
 Y_t &= x'_t\beta + z'_t\delta_2 + u_t & t = T_1 + 1, \dots, T_2 \\
 &\dots \\
 Y_t &= x'_t\beta + z'_t\delta_j + u_t & t = T_{j-1} + 1, \dots, T_j \quad j = 1, \dots, m
 \end{aligned}
 \tag{1}$$

In equation (1), x'_t (px1) and z'_t (qx1) represent vectors of independent variables, β and δ_1 are coefficient vectors, and u_t is the pure error term. With $T_0 = 0$ and $T_{m+1} = T$, the unknown break points T_1, T_2, \dots, T_m are to be determined. The primary objective of the Bai-Perron test is to simultaneously estimate the unknown regression coefficients $\beta, \delta_1, \dots, \delta_m$ and the break times T_1, T_2, \dots, T_m . It is assumed that the number of observations T and the values of Y_t, x'_t and z'_t are known. Since the estimation is performed using the entire sample and the β value remains constant, the model is considered a partial structural change model.

In the model based on the least squares method, the least squares estimates of β and δ_j for all m segments denoted by T_j are obtained by minimizing the sum of squared residuals.⁴

$$S_T(T_1, T_2, \dots, T_m) = \sum_{t=1}^{m+1} \sum_{t=T_{t-1}}^{T_t} [y_t - x'_t\beta - z'_t\delta_j]^2
 \tag{2}$$

The equation is calculated, and the results are denoted as $\hat{\beta}\{T_j\}, \hat{\delta}\{T_j\}$. The estimated values are incorporated into the objective function, and the sum of squared residuals is expressed as $S_T(T_1, T_2, \dots, T_m)$. The estimated break points $(\hat{T}_1, \hat{T}_2, \dots, \hat{T}_m)$ are calculated as follows: (Bai and Perron, 1998, 2003)

$$(\hat{T}_1, \hat{T}_2, \dots, \hat{T}_m) = \underset{T_1, T_2, \dots, T_m}{\operatorname{argmin}}
 \tag{3}$$

During the calculation, the minimization condition $T_i - T_{i-1} \geq [\varepsilon T]^2$ is applied across all segments (T_1, T_2, \dots, T_m) . Therefore, the break point estimators are the global minimizers of the objective function.

Finally, the regression parameter estimates in the estimated $\{\hat{T}_j\}$, are the associated least squares estimates (e.g. $\hat{\delta} = \hat{\delta}(\{\hat{T}_j\})$)

Bai and Perron recommended the use of three test statistics to determine the number of breaks:

$$\operatorname{Sup}F_T(k)$$

1. The $\operatorname{Sup}F_T(k)$ test, which compares the null hypothesis of no breaks against the alternative hypothesis of k breaks.

$$UD_{\max}F_T \quad WD_{\max}F_T$$

2. The double maximum tests, $UD_{\max}F_T$ and $WD_{\max}F_T$, which compare the null hypothesis of no breaks against the alternative hypothesis of an unknown number of breaks.

$$\operatorname{Sup}F_T(l + 1|l)$$

3. The $\operatorname{Sup}F_T(l + 1|l)$ test, which compares the null hypothesis of l breaks against the alternative hypothesis of l+1 breaks.

⁴ If $\beta = 0$, this results in a pure structural change model where all coefficients are subject to change.

Bai and Perron recommended the use of three information criteria to determine the number of multiple breaks. The first is the Bayesian Information Criterion developed by Yao (1988), the second is the modified Schwarz Information Criterion (LWZ Criterion) proposed by Liu et al. (1994), and the third is $\text{SupF}_T(l + 1|l)$

the sequential information criterion stemming from the sequential application of the test, developed by Bai and Perron (2003). Bai and Perron stated that conducting one of the first two tests to identify the existence of breaks, followed by the application of the sequential criterion to discover the number of breaks, is considered more reliable.

3. Climate Change Literature in Türkiye

When examining the literature on climate change in Türkiye, it is evident that most studies focus on specific regions, while relatively few address the country as a whole. The nationally scoped studies relevant to our work are summarized below.

Giorgi (2006), in his 21st-century climate change projections, identified the Mediterranean Basin as one of the regions most vulnerable to the impacts of climate change. Similarly, the IPCC's Fourth Assessment Report (2007), using Global Circulation Model projections under various emission scenarios, predicted that the Mediterranean Basin—including Türkiye—would encounter substantial temperature increases and reductions in precipitation towards the close of the century.

Tayanç et al. (2009) analyzed temperature and precipitation data from both urban and rural meteorological stations across Türkiye for the period 1950–2004. Their results revealed a marked increase in temperatures, particularly after 1993, with minimum temperatures rising due to the effects of urbanization. They also observed increased variability in precipitation, a key contributor to flood events. Regionally, temperature increases were widespread, while precipitation declined in the Aegean and Thrace regions and rose in the north.

Lelieveld et al. (2012) projected that daytime maximum temperatures would rise most rapidly in the Balkan Peninsula and Türkiye, accompanied by a reduction in annual precipitation across southern Europe, Türkiye, and the eastern Mediterranean.

Toros (2012), using data from 165 stations covering 1961–2008, found that temperatures began rising in the early 1980s. Increases in maximum temperatures during warm seasons were more pronounced than in cooler periods. A comparison of monthly averages between 1961–1984 and 1985–2008 at nine stations showed significant increases in extreme temperatures across regions.

Şen et al. (2013) also identified a statistically significant rise in temperatures across Türkiye during the 1970–2011 period.

In addition to national-level analyses, numerous studies have focused on specific regions of Türkiye, offering further insight into localized climate trends.

Kitoh et al. (2008) projected a substantial decline in precipitation in the Euphrates Basin by the end of the 21st century. Similarly, Fujihara et al. (2008) focused on the Çukurova region, estimating a future reduction in snow buildup and surface runoff in the Seyhan Basin. Expanding on this, Kurt (2020) found statistically significant increases in temperature and decreases in precipitation in the Çukurova region (1970–2017), with coastal and central zones most affected.

Önol and Semazzi (2009), in their analysis of 21st-century climate projections for Türkiye, anticipated slight increases in precipitation along the Black Sea shore and notable declines along the Mediterranean and Aegean coasts.

Yavuz and Erdoğan (2011), using data from 120 rain gauge stations (1978–2008), reported a significant downward trend in total precipitation from January to May. In contrast, increases were observed in August, October, and December. A positive precipitation trend was noted in the eastern Black Sea region, while the Tuz Gölü region showed consistent monthly declines, particularly in central Türkiye.

Vardar et al. (2011), examining districts in Bursa (1975–2005), found statistically significant increases in both maximum and minimum temperatures.

Yılmaz (2015), investigating extreme precipitation events in Antalya using data from seven observation stations, reported a notable surge in such occurrences, especially in the city center. Supporting this, Kadioğlu (2018) linked frequent flooding in Antalya to intense convective precipitation.

Polat (2020), in a study on the Konya Closed Basin—Türkiye’s fourth-largest basin—projected a temperature increase between 0.7°C and 5.9°C and a reduction in precipitation by 50–150 mm by century’s end.

Finally, Şener (2021), focusing on the Eğirdir Lake Basin, identified statistically significant upward trends in temperature and mixed trends in precipitation. While Uluborlu and Yalvaç experienced declining precipitation, other areas showed increasing trends.

4. Data and Methodology

The study utilized monthly average temperature data from 56 stations, spanning the timeframe from 1950 to 2021, obtained from the Turkish State Meteorological Service. Stations with missing data for any month were excluded when calculating annual averages. After identifying which NUTS-2 region each station belongs to, annual temperature averages for each NUTS-2 region were calculated, resulting in 72-year time series.

NUTS system, developed by the European Union's Statistical Office (Eurostat) and first approved by the European Parliament and Council in 2003, has a hierarchical structure. In this classification, a country is first separated into Level 1 regions, which are then segmented further into Level 2 regions, and finally, these are additionally divided into Level 3 regions.⁵ The classification has three main objectives: the accumulation, improvement, and harmonization of regional statistics; conducting socio-economic analyses of regions; and determining the framework for regional policies.⁶ At the Brussels Conference held in 1961, NUTS regions were discussed, and it was concluded that Level 2 regions, generally used in shaping regional policy frameworks, are the most appropriate scale for analyzing national-regional issues. (Öztürk, 2009)

Bai and Perron (2006) noted that structural break tests may exhibit biases in small sample sizes, so the study increased the sample size. To enhance the number of observations in the analysis, the average of 12 months from June to the following June was also calculated, and these two sets were combined to create time series with 144 observations for each region. This boosted the sample size and improve the robustness of analysis.

In the structural break analysis conducted in the study, the Bai-Perron method was employed, as the primary objective was to identify unknown break dates. We test the following model for structural breaks:

$$y_t = c + \epsilon_t \quad (4)$$

where y is the temperature or precipitation, c denotes a constant term, and ϵ is the error term.

The analyses were performed using the EViews software. The analysis was repeated for each region individually. As a first step, following Bai and Perron (2003), two separate equations were estimated using the least squares method, with temperature and precipitation as dependent variables and a single independent variable, a constant.

To account for serial correlation in the errors during the estimation process, a second-order spectral kernel-based heteroskedasticity and autocorrelation consistent (HAC) covariance specification was applied using prewhitened⁷ residuals. A fixed one-period lag was specified for the prewhitening process. The kernel bandwidth was determined using the Andrews AR (1) method.

After the estimation, the $\text{SupF}_T(k)$ test (comparing the null hypothesis of no breaks against the

⁵ <https://ec.europa.eu/eurostat/web/nuts/history>

⁶ <https://ec.europa.eu/eurostat/web/nuts/background>

⁷ Prewhitening is the most frequently applied method in trend analysis to remove the influence of serial correlation (Bayazit and Önöz, 2007).

alternative hypothesis of k breaks) was conducted to detect the presence of breaks. Subsequently, the $\text{SupF}_T(l+1|l)$ test (a sequential test of $l+1$ breaks against l breaks) was used to determine the number and timing of breaks. A default trimming percentage of 15% and a 95% significance level were applied during the test. Additionally, to allow for error heterogeneity, the error distributions were permitted to vary across breaks.

Figure 2 exhibits the break dates after 1990 which are identified from the analysis.

5. Results

The break years identified for the temperature data are presented in Table 2. While the timing of structural breaks varies across regions, some were observed as early as the late 1950s and 1960s. However, structural breaks in temperature were detected in all but one of the 26 NUTS-2 regions during the late 1990s and early 2000s.

In contrast, when precipitation data were analyzed using the same method, no structural breaks were found during the study period. Nonetheless, by using the temperature break years as reference points, significant regional variations in precipitation patterns were detected.

Table 2: Structural Break Times and Average Increase Amounts in Temperature for NUTS-2 Regions

Region	Break Years
TR10-İstanbul Sub Region	1953, 1967, 1999
TR21-Tekirdağ Sub Region	1953, 1967, 1998
TR22-Balıkesir Sub Region	1953, 1999
TR31-İzmir Sub Region	1953, 1964, 1999
TR32-Aydın Sub Region	1959, 1964, 1998
TR33-Manisa Sub Region	1953, 1964, 1998
TR41-Bursa Sub Region	1964, 1998
TR42-Kocaeli Sub Region	1998
TR51-Ankara Sub Region	2001
TR52-Konya Sub Region	2001
TR61- Antalya Sub Region	1967, 1998
TR62- Adana Sub Region	1959, 1998
TR63- Hatay Sub Region	1964, 1998
TR71-Kırıkkale Sub Region	2001
TR72-Kayseri Sub Region	1967, 1998
TR81-Zonguldak Sub Region	1953, 1998
TR82-Kastamonu Sub Region	1964, 1998
TR83-Samsun Sub Region	1967, 1998
TR90-Trabzon Sub Region	1956, 1998
TRA1 ⁸ -Erzurum Sub Region	-
TRA2-Ağrı Sub Region	1959, 1994
TRB1- Malatya Sub Region	2001
TRB2-Van Sub Region	1956, 1994
TRC1- Gaziantep Sub Region	1998
TRC2- Şanlıurfa Sub Region	1998
TRC3- Mardin Sub Region	1998

Source: Authors' calculations.

When applying the Bai-Perron test for a single structural break (with a 0.15 trimming parameter and a 0.05 significance level), breaks were found in the 1990s for 20 of the 26 regions, and in 2001 for five regions (TR51, TR52, TR71, TR83, and TRB1). No structural break was detected in the TRA1 region.

⁸ No structural break is found with a 0.15 trimming and a 0.1 significance level. However, with a 0.05 trimming and a 0.1 significance level, a break is identified in 2010.

5.1 Temperature Changes

Based on the analysis results—and focusing on the most recent break dates, which occurred in the 1990s and early 2000s—Table 3 presents the average temperatures before and after the structural break for each region, along with the differences.

Except for the TRA1 region, all regions experienced a structural break in temperature. In every case, temperatures increased following the break.

Overall, temperature increases were more pronounced in Eastern Anatolia and Thrace, while coastal areas (except Adana and Mersin) experienced smaller changes. Consistent with previous studies, the Black Sea region exhibited relatively moderate temperature increases. The largest change was observed in the TRB2 region, while the smallest occurred in TR81.

In the Western, Central, and Eastern Black Sea regions, the increase remained below 1 °C, whereas in the Marmara region it exceeded 1 °C. Within the Mediterranean region, only the Adana–Mersin subregion showed an increase above 1 °C. In Central Anatolia, the temperature rise exceeded 1 °C except in the Konya–Karaman area. Similarly, in Eastern Anatolia, temperatures rose more than 1 °C in all areas except Bayburt, Erzincan, and Erzurum. Southeastern Anatolia also showed increases above 1 °C, except in the Diyarbakır and Şanlıurfa subregions. The results are consistent with all sources cited in the literature review section.

The magnitude and regional distribution of these temperature changes are visualized in Figure 1.

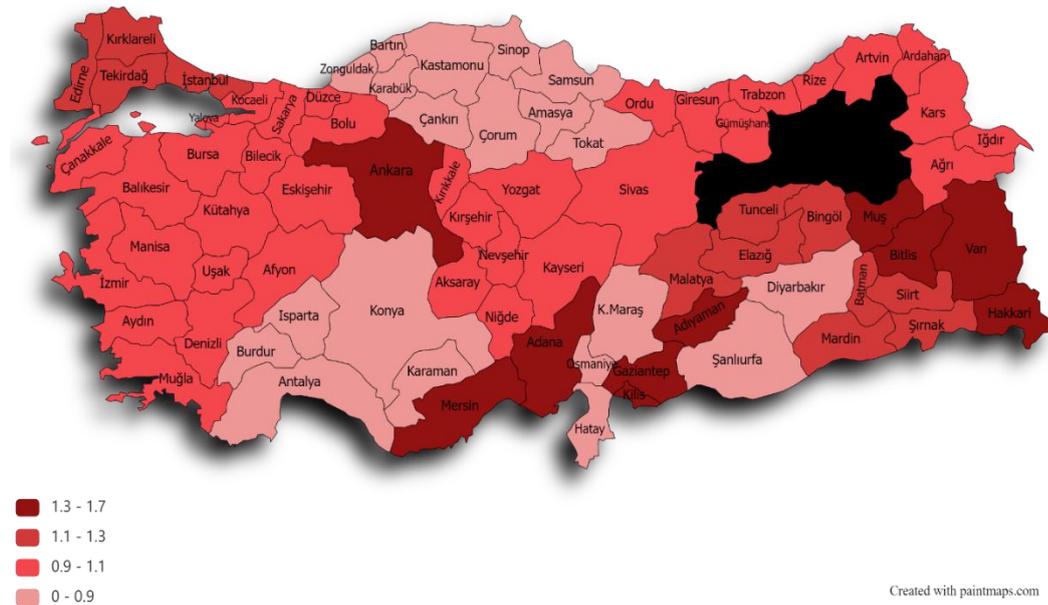
Table 3: Structural Break Years and Average Temperature Increase Amounts for NUTS-2 Regions

Region	Last Break Year	Pre-Break Average	Post-Break Average	Post-Pre Difference
TR10-İstanbul Sub Region	1999	13.92	15.18	1.26
TR21-Tekirdağ Sub Region	1998	13.12	14.35	1.23
TR22-Balıkesir Sub Region	1999	14.47	15.52	1.05
TR31-İzmir Sub Region	1999	17.04	17.94	0.90
TR32-Aydın Sub Region	1998	18.21	19.19	0.98
TR33-Manisa Sub Region	1998	13.27	14.20	0.93
TR41-Bursa Sub Region	1998	13.27	14.28	1.01
TR42-Kocaeli Sub Region	1998	10.16	11.16	1.00
TR51-Ankara Sub Region	2001	11.67	12.97	1.30
TR52-Konya Sub Region	2001	11.48	12.35	0.87
TR61- Antalya Sub Region	1998	14.53	15.34	0.81
TR62- Adana Sub Region	1998	19.00	20.32	1.32
TR63- Hatay Sub Region	1998	19.09	19.86	0.77
TR71-Kırıkkale Sub Region	2001	11.06	12.16	1.10
TR72-Kayseri Sub Region	1998	9.35	10.42	1.07
TR81-Zonguldak Sub Region	1998	13.57	14.34	0.77
TR82-Kastamonu Sub Region	1998	11.58	12.36	0.78
TR83-Samsun Sub Region	1998	12.07	12.88	0.81
TR90-Trabzon Sub Region	1998	13.51	14.48	0.97
TRA1 ⁹ -Erzurum Sub Region	-			
TRA2-Ağrı Sub Region	1994	4.76	5.82	1.06
TRB1- Malatya Sub Region	2001	13.12	14.37	1.25
TRB2-Van Sub Region	1994	8.91	10.37	1.46
TRC1- Gaziantep Sub Region	1998	14.8766	16.30	1.43
TRC2- Şanlıurfa Sub Region	1998	16.96	17.77	0.81
TRC3- Mardin Sub Region	1998	15.76	17.02	1.26

Source: Authors' calculations.

⁹ No structural break is found with a 0.15 trimming and a 0.1 significance level. However, with a 0.05 trimming and a 0.1 significance level, a break is identified in 2010.

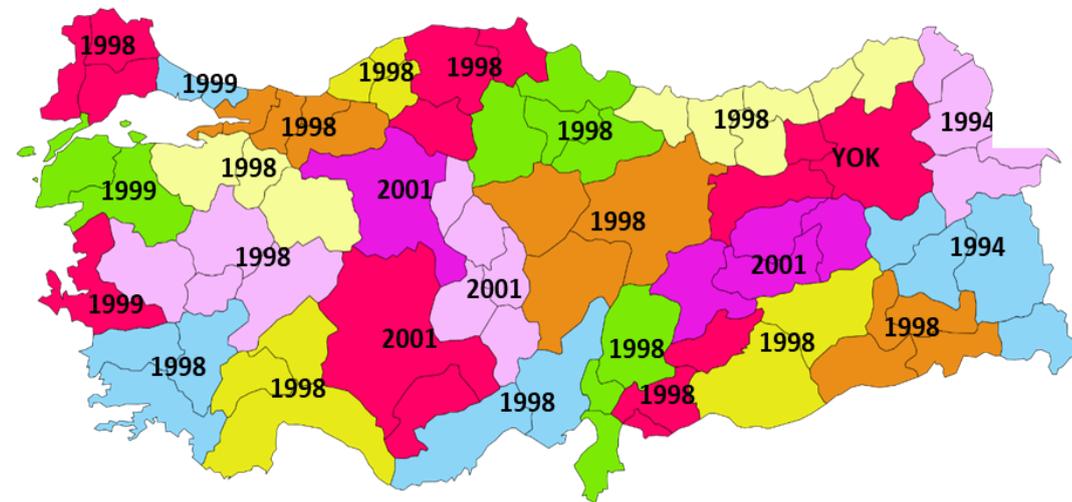
Figure 1: Regional Temperature Changes in Türkiye (1950-2021)-Heat Map



Source: Created by the authors.

An examination of Figure 2 shows that the earliest structural breaks in temperature occurred in 1994 in the eastern part of Eastern Anatolia, while the most recent were observed in 2001 in parts of Central Anatolia and western Eastern Anatolia. Overall, the most frequently observed break years are 1998 and 1999.

Figure 2: Structural Break Dates of Temperature Increases in NUTS-2 Regions in Türkiye



Source: Created by the authors.

5.2 Temperature Change: Urbanization and Industrialization

In this study, we also investigate the relationship between temperature change and two key socioeconomic indicators: urbanization and industrialization due to the presence of structural break in temperature levels. To explore the potential effects, we estimated two separate regression equations using the ordinary least squares (OLS) method.

The dependent variable in both equations is the temperature change, defined as the difference in average temperature between the periods before and after the identified structural breakpoint year for each region. The independent variables are the urbanization rate and the industrialization rate, respectively. These variables were selected to assess whether demographic and economic transformations have

contributed to regional climate trends.

The basic regression model can be specified as follows:

$$\Delta T_i = \alpha + \beta_1 X_i + \epsilon_i \tag{5}$$

where ΔT_i is the change in average temperature in region i , X_i is either the urbanization rate or the industrialization rate in region i , α is the constant term, β_1 is the coefficient of interest, and ϵ_i is the error term.

The results of the regressions are presented in Table 4. The findings indicate that urbanization has a statistically significant positive association with temperature change. Specifically, this relationship is significant at the 90% confidence level, suggesting that regions with higher urbanization rates have experienced more pronounced increases in temperature.

Table 4: Impact of Urbanization and Industrialization on the Temperature Change

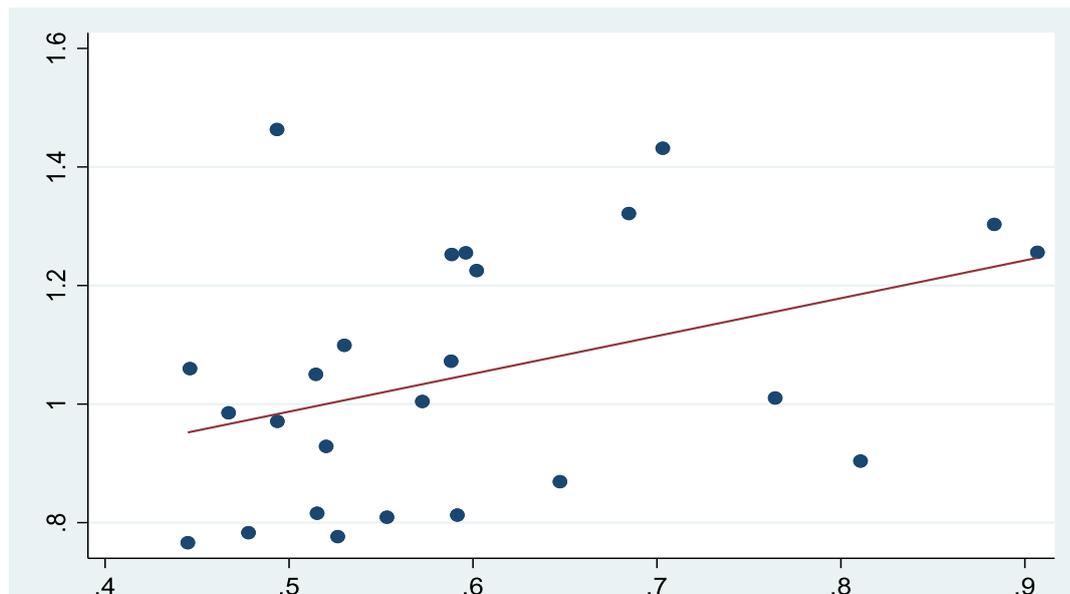
	Model (1)	Model (2)
Urbanization	0.64* (0.32)	
Industrialization		0.23 (0.53)
Constant	0.67	1.01
R-squared	0.1502	0.0081
Note: *: $p < 0.1$, standard errors in the parenthesis.		

Source: Calculated by the authors.

In contrast, the analysis did not find a statistically significant relationship between temperature change and industrialization rates. This result implies that, within the scope of this study, industrial development does not appear to have a measurable impact on regional temperature trends.

To further illustrate the findings, a scatter plot is provided in Figure 3. The plot visualizes the relationship between temperature change and urbanization across the 26 NUTS-2 regions, highlighting the upward trend consistent with the regression results.

Figure 3: The Relationship Between Temperature Change and Urbanization



Source: Calculated by the authors.

5.3 Changes in Precipitation Amounts

When the Bai-Perron test was applied to precipitation data, it generally revealed no structural breaks.

However, when break years identified in regional temperature data were used as reference points, statistically significant shifts in precipitation patterns were detected. (Table 5)

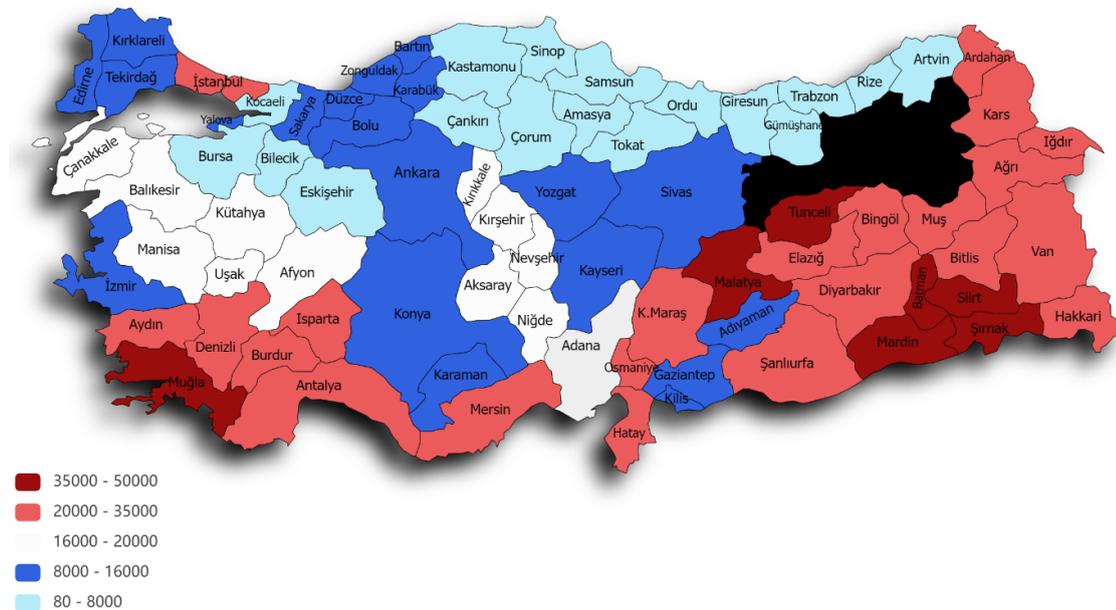
Specifically, precipitation levels decreased in the Western Marmara, Aegean, Mediterranean, Eastern Anatolia, and Southeastern Anatolia regions. In contrast, increases were observed in the Eastern Marmara, Central Anatolia, and Black Sea regions. (Figure 4)

Table 5: Changes in Precipitation Amounts in NUTS-2 Regions

Region	Temperature Structural Break Year	Pre-Break Precipitation Average	Post-Break Precipitation Average	Post-Pre Difference
TR10-İstanbul Sub Region	1999	60.36	57.58	-2.78
TR21-Tekirdağ Sub Region	1998	51.21	51.57	0.36
TR22-Balıkesir Sub Region	1999	58.26	58.09	-0.17
TR31-İzmir Sub Region	1999	62.19	63.85	1.66
TR32-Aydın Sub Region	1998	84.13	80.91	-3.22
TR33-Manisa Sub Region	1998	49.87	49.82	-0.05
TR41-Bursa Sub Region	1998	47.50	51.36	3.86
TR42-Kocaeli Sub Region	1998	46.16	48.38	2.22
TR51-Ankara Sub Region	2001	33.74	34.29	0.55
TR52-Konya Sub Region	2001	27.40	29.48	2.08
TR61- Antalya Sub Region	1998	60.28	55.49	-4.79
TR62- Adana Sub Region	1998	70.77	68.49	-2.28
TR63- Hatay Sub Region	1998	83.09	82.13	-0.96
TR71-Kırıkkale Sub Region	2001	30.97	30.98	0.01
TR72-Kayseri Sub Region	1998	39.66	40.62	0.96
TR81-Zonguldak Sub Region	1998	101.84	102.91	1.07
TR82-Kastamonu Sub Region	1998	42.64	48.42	5.78
TR83-Samsun Sub Region	1998	42.63	45.50	2.87
TR90-Trabzon Sub Region	1998	115.03	122.15	7.12
TRA1 ¹⁰ -Erzurum Sub Region	-			
TRA2-Ağrı Sub Region	1994	45.26	40.95	-4.31
TRB1- Malatya Sub Region	2001	36.53	33.17	-3.36
TRB2-Van Sub Region	1994	34.02	33.82	-0.20
TRC1- Gaziantep Sub Region	1998	53.12	54.54	1.42
TRC2- Şanlıurfa Sub Region	1998	47.59	43.39	-4.20
TRC3- Mardin Sub Region	1998	70.72	58.46	-12.26

Source: Authors’ calculations.

Figure 4: Regional Precipitation Change in Türkiye (1950-2021)-Heat Map



¹⁰ No structural break is found with a 0.15 trimming and a 0.1 significance level. However, with a 0.05 trimming and a 0.1 significance level, a break is identified in 2010.

Table 6: Changes in Precipitation Amounts in NUTS-2 Regions in Türkiye, t-Test Results

Region	Break Year	Test Result	Statistically Significant?
TR10-İstanbul Sub Region	1999	0.34	No
TR21-Tekirdağ Sub Region	1998	0.93	No
TR22-Balıkesir Sub Region	1999	0.96	No
TR31-İzmir Sub Region	1999	0.68	No
TR32-Aydın Sub Region	1998	0.48	No
TR33-Manisa Sub Region	1998	0.98	No
TR41-Bursa Sub Region	1998	0.11	No
TR42-Kocaeli Sub Region	1998	0.21	No
TR51-Ankara Sub Region	1998	0.77	No
TR52-Konya Sub Region	2001	0.25	No
TR61- Antalya Sub Region	1998	0.21	No
TR62- Adana Sub Region	1998	0.66	No
TR63- Hatay Sub Region	1998	0.78	No
TR71-Kırıkkale Sub Region	2001	0.10	No
TR72-Kayseri Sub Region	1998	0.55	No
TR81-Zonguldak Sub Region	1998	0.79	No
TR82-Kastamonu Sub Region	1998	0.0038	Yes*
TR83-Samsun Sub Region	1998	0.07	Yes**
TR90-Trabzon Sub Region	1998	0.04	Yes*
TRA1 ¹¹ -Erzurum Sub Region	-		
TRA2-Ağrı Sub Region	1994	0.03	Yes*
TRB1- Malatya Sub Region	2001	0.08	Yes**
TRB2-Van Sub Region	1994	0.90	No
TRC1- Gaziantep Sub Region	1998	0.70	No
TRC2- Şanlıurfa Sub Region	1998	0.22	No
TRC3- Mardin Sub Region	1998	0.0036	Yes*

Note: *: $p < 0.05$, **: $p < 0.1$

Source: Authors' calculations.

To determine whether changes in precipitation are statistically significant, a t-test was performed. The results are presented in Table 6.

According to the t-test results, changes in precipitation are statistically significant in six regions. Specifically, significant changes were found in the Central and Eastern Black Sea regions and the Malatya Subregion (Malatya, Elazığ, Bingöl, and Tunceli) at the 90% confidence level. At the 95% confidence level, significant changes were observed in the Ağrı Subregion (Ağrı, Iğdır, Ardahan, and Kars) and the Mardin Subregion (Mardin, Batman, Şırnak, and Siirt). No statistically significant changes were found in the remaining regions, suggesting that structural breaks in precipitation have not yet occurred there. The results align with Kitoh et al.(2008) for the Malatya Subregion, with Yavuz and Erdoğan (2011) for the Black Sea Region, and, although not statistically significant, with Kurt (2020) and Fujihara et al. (2008) for the Adana Subregion.

Structural breaks in temperature and precipitation may have far-reaching implications for various economic sectors—particularly agriculture—by influencing productivity and, consequently, price dynamics. Furthermore, persistent changes in climate can affect the frequency and severity of natural disasters, trigger inter-regional migration, alter settlement patterns, and pose challenges to public health. These impacts underscore the importance of further research into the long-term socioeconomic consequences of climate change in Türkiye.

6. Conclusion

Climate refers to the long-term fluctuation of temperature, precipitation, and similar atmospheric variables over a specific period. The earliest indicators of climate change are typically observed through shifts in temperature and precipitation levels. These changes allow for inferences about the climate dynamics of a particular region or country.

¹¹ No structural break is found with a 0.15 trimming and a 0.1 significance level. However, with a 0.05 trimming and a 0.1 significance level, a break is identified in 2010.

This study uses data from the Turkish State Meteorological Service (MGM) for the period 1950–2021 to detect structural breaks in Türkiye’s temperature and precipitation patterns. The analysis revealed that, with the exception of the TRA1 region (Erzurum Sub Region), all 25 NUTS-2 regions experienced at least one structural break in temperature during this period. No structural break was detected in precipitation trends. However, when precipitation data were analyzed in relation to the break years identified in temperature, statistically significant changes were observed. Specifically, precipitation decreased in the Eastern and Southeastern Anatolia regions, while it increased in the Black Sea region.

According to the structural break analysis, the most recent break year in all regions—except TRA2 (Ağrı Sub Region)—occurred in the late 1990s or early 2000s. A comparison of average temperatures before and after the identified break years confirms that temperatures increased in all regions of Türkiye between 1950 and 2021, though the extent of this increase varied. The most pronounced temperature rises occurred in the Eastern Anatolia region, while the Western Black Sea region experienced the smallest increase. Among the three most populous provinces—Ankara, Istanbul, and İzmir—all saw rising temperatures, with Ankara recording the highest increase.

The relationship between temperature change, urbanization, and industrialization has also been examined in this study. The results show that temperature change is statistically associated with urbanization. As urban areas grow, their influence on local temperature trends becomes more evident. In contrast, the analysis did not reveal any statistically significant relationship between temperature change and industrialization. This suggests that, within the scope of this study, industrial activity may not have played a measurable role in regional temperature variation.

The regions most adversely affected by climate change appear to be Eastern and Southeastern Anatolia, where both rising temperatures and declining precipitation were observed. Conversely, the Black Sea region seems to be the least affected, with relatively moderate temperature increases and a noticeable rise in precipitation.

Changes in temperature and precipitation regimes can have both negative and positive effects on economic activities. These shifts influence agricultural production by altering crop patterns and yields and affect energy generation through their impact on river flows. In addition, temperature increases and changing precipitation patterns can shorten or extend construction periods, thereby affecting the construction industry, the services sector—particularly tourism—and various public services.

If these trends persist, they may also significantly influence the frequency and distribution of natural disasters, with substantial consequences for quality of life. Rising temperatures and reduced precipitation increase the risk of droughts and wildfires, while changes in precipitation patterns could lead to more frequent floods and inundations. These realities underscore the need for climate-resilient planning across all economic sectors. For example, irrigation systems, urban development, and disaster preparedness strategies must be designed with climate change projections in mind.

While this study provides robust regional estimates, future research could expand by focusing on monthly extremes or by integrating socioeconomic variables (e.g., urbanization, population density) to better assess how weather events disrupt various economic sectors.

References

- Ali, E., W. Cramer, J. Carnicer, E. Georgopoulou, N.J.M. Hilmi, G. Le Cozannet, & P. Lionello, (2022). Cross-Chapter Paper 4: Mediterranean Region. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, ABD, pp. 2233–2272.
- Andrews, D. W. (1993). Tests for parameter instability and structural change with unknown change point. *Econometrica: Journal of the Econometric Society*, 821-856. <https://doi.org/10.2307/2951764>
- Atalay, İ. (1997). Türkiye coğrafyası. *Ege Üniversitesi Basımevi*.

- Bai, J., & Perron, P. (1998). Estimating and testing linear models with multiple structural changes. *Econometrica*, 47-78. <https://doi.org/10.2307/2998540>
- Bai, J., & Perron, P. (2003). Critical values for multiple structural change tests. *The Econometrics Journal*, 6(1), 72-78. <https://doi.org/10.1111/1368-423X.00102>
- Bai, J. & Perron, P. (2006). Multiple Structural Change Models: A Simulation Analysis, in *Econometric Theory and Practice: Frontier of Analysis and Applied Research (Essays in Honor of Peter Phillips)*, ed. by Corbae D., S. Durlauf and B.E. Hansen, Cambridge University Press. <https://doi.org/10.1017/CBO9781139164863.010>
- Bayazit, M., & Önöz, B. (2007). To prewhiten or not to prewhiten in trend analysis?, *Hydrological Sciences Journal*, 52(4), 611–624. <https://doi.org/10.1623/hysj.52.4.611>
- Chow, G. C. (1960). Tests of equality between sets of coefficients in two linear regressions. *Econometrica: Journal of the Econometric Society*, 591-605. <https://doi.org/10.2307/1910133>
- Ericsson, N. R. (2011). Justifying Empirical Macro-Econometric Evidence In Practice. Working Paper.
- Ericsson, N. R., Dore, M. H. I., & Butt H. 2022. Detecting and Quantifying Structural Breaks in Climate. *Econometrics* 10: 33. <https://doi.org/10.3390/econometrics10040033>
- Fujihara, Y., Tanaka, K., Watanabe, T., Nagano, T. & Kojiri, T. (2008). Assessing the impacts of climate change on the water resources of the Seyhan River Basin in Turkey: Use of dynamically downscaled data for hydrologic simulations, *Journal of Hydrology*, 353: 33-48. <https://doi.org/10.1016/j.jhydrol.2008.01.024>
- Giorgi, F. (2006). Climate change hot-spots, *Geophysical Resource Letters.*, Vol 3, L08707. doi:10.1029/2006GL025734,
- Hansen, B. E. (1992). Testing for parameter instability in linear models. *Journal of Policy Modeling*, 14(4), 517-533. [https://doi.org/10.1016/0161-8938\(92\)90019-9](https://doi.org/10.1016/0161-8938(92)90019-9)
- Houghton, J. (2005). *Global warming, Reports on progress in physics*, Institute of Physics Publishing, 68(6), 1343. <https://doi.org/10.1088/0034-4885/68/6/R02>
- IPCC (2001) Intergovernmental panel on climate change. Climate change 2001–the scientific basis: contribution of working group I to the third assessment report of the intergovernmental panel on climate change. In: Houghton JT et al (eds) Cambridge University Press, New York.
- IPCC (2007) Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Theme], Pachauri R. K., Reisinger A. (eds). IPCC: Geneva; 104.
- Kitoh, A., A. Yatagai, P. & Alpert, (2008). First super-high-resolution model projection that the ancient Fertile Crescent will disappear in this century, *Hydrological Resource Letters.*, 2, 1–4. <https://doi.org/10.3178/hrl.2.1>
- Kurt, D. (2020), İklim Değişikliğinin Çukurova Bölgesi Su Kaynakları Üzerine Olan Etkilerinin Değerlendirilmesi, Yüksek Lisans Tezi, Çukurova Üniversitesi, Fen Bilimleri Enstitüsü.
- Lelieveld, J., Hadjinicolaou, P., Kostopoulou, E., Chenoweth, J., El Maayar, M., Giannakopoulos, C., Hannides, C., Lange, M. A., Tanarhte, M., Tyrlis, E. & Xoplaki, E. (2012). Climate change and impacts in the Eastern Mediterranean and the Middle East, *Climatic Change*, 114, 667-687. <https://doi.org/10.1007/s10584-012-0418-4>
- Liu, Y., Cizeau, P., Meyer, M., Peng, C. K., & Stanley, H. E. (1997). Correlations in economic time series. *Physica A: Statistical Mechanics and its Applications*, 245(3-4), 437-440. [https://doi.org/10.1016/S0378-4371\(97\)00368-3](https://doi.org/10.1016/S0378-4371(97)00368-3)
- Llasat, M.C., Llasat-Botija, M., Petrucci, O., Pasqua, A. A., Rosselló, j., Vinet, F., & Boissier, L. (2016). Trends in flash flood events versus convective precipitation in the Mediterranean region: the case of Catalonia. *Journal of Hydrology: Regional Studies*, 541, 24–37.

<https://doi.org/10.1016/j.jhydrol.2016.05.040>

- MGM (2015). Yeni Senaryolar ile Türkiye İklim Projeksiyonları ve İklim Değişikliği, Meteoroloji Genel Müdürlüğü Matbaası, Ankara.
- Nordhaus, W. (2013). The climate casino: Risk, uncertainty, and economics for a warming world. Cesi Mizrahi (Çev.). İstanbul: Doğan Kitap.
- Nyblom, J. (1989). Testing for the constancy of parameters over time. *Journal of the American Statistical Association*, 84(405), 223-230. <https://doi.org/10.1080/01621459.1989.10478759>
- Önol, B. & Semazzi, F.H.M. (2009). Regionalization of climate change simulations over Eastern Mediterranean. *Journal of Climatology*, 22:1944-1961. <https://doi.org/10.1175/2008JCLI1807.1>
- Öztürk A., (2009). “Homojen ve Fonksiyonel Bölgelerin Tespiti ve Türkiye İçin İstatistikî Bölge Birimleri Önerisi”, Uzmanlık Tezi, Devlet Planlama Teşkilatı.
- Perron, P. (1989). The great crash, the oil price shock, and the unit root hypothesis. *Econometrica: Journal of the Econometric Society*, 1361-1401. <https://doi.org/10.2307/1913712>
- Polat, Ç. (2020). İklim Değişikliğinin Konya Kapalı Havzası Üzerindeki Olası Etkileri, Yüksek Lisans Tezi, Ankara Üniversitesi Sosyal Bilimler Enstitüsü.
- Quandt, R. E. (1958). The estimation of the parameters of a linear regression system obeying two separate regimes. *Journal of The American Statistical Association*, 53(284), 873-880. <https://doi.org/10.1080/01621459.1958.10501484>
- Quandt, R. E. (1960). Tests of the hypothesis that a linear regression system obeys two separate regimes. *Journal of the American Statistical Association*, 55(290), 324-330. <https://doi.org/10.1080/01621459.1960.10482067>
- Rahmstorf, S., & Schellnhuber, H. J. (2020). İklim Değişikliği Teşhisi, Tahmini, Çözümü. Hülya Kaya (Çev.). Runik Kitap.
- Şen, Ö. L., Bozkurt, D., Göktürk, O. M., Dündar, B., & Altürk, B. (2013). Türkiye’de iklim değişikliği ve olası etkileri. *Taşkın Sempozyumu*, 29, 30.
- Şener, Ş. (2021). Küresel İklim Değişikliğinin Eğirdir Gölü Havzasına Etkileri ve Kuraklık Analizi, Doktora Tezi, Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü.
- Tayanç, M., İm, U., Doğruel, M., & Karaca, M. (2009). Climate change in Turkey for the last half century. *Climatic Change*, 94(3), 483-502. <https://doi.org/10.1007/s10584-008-9511-0>
- Toros, H. (2012). Spatio-temporal variation of daily extreme temperatures over Turkey. *International Journal of Climatology*, 32(7), 1047-1055. <https://doi.org/10.1002/joc.2325>
- Ulubaşoğlu, M. A., Rahman, M. H., Önder, Y. K., Chen, Y., & Rajabifard, A. (2019). Floods, bushfires and sectoral economic output in Australia, 1978–2014. *Economic Record*, 95(308), 58-80. <https://doi.org/10.1111/1475-4932.12446>
- Vardar, A., Kurtulmuş, F., & Darga, A. (2011). Local indications of climate changes in Turkey: Bursa as a case example. *Climatic Change*, 106(2), 255-266. <https://doi.org/10.1007/s10584-010-9904-8>
- Yao, Y.C. (1988) Estimating the number of change-points via Schwarz’ criterion, *Statistics and Probability Letters*, 6, 181–89.
- Yao, Y.C. & Au, S. T. (1989) Least squares estimation of a step function, *Sankhya*, 51 Series A, Pt 3, 370–381.
- Yavuz, H., & Erdoğan, S. (2012). Spatial analysis of monthly and annual precipitation trends in Turkey. *Water Resources Management*, 26(3), 609-621. <https://doi.org/10.1007/s11269-011-9935-6>
- Yılmaz, A. G. (2015). The effects of climate change on historical and future extreme rainfall in Antalya,

Turkey. *Hydrological Sciences Journal*, 60(12), 2148-2162.
<https://doi.org/10.1080/02626667.2014.945455>

Yin, Y. Q. (1988) Detection of the number, locations and magnitudes of jumps, *Communications in Statistics–Stochastic Models*, 4, 445–55.

Arastırma Makalesi

Climate Change In Türkiye: Evidence From A Structural Break Analysis

Türkiye’de İklim Değişikliği: Yapısal Kırılma Analizinden Kanıtlar

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Genişletilmiş Özet

Sanayi Devrimi sonrası dünya, üretim ve tüketimde büyük bir artış yaşamış, bu da fosil yakıtlar gibi üretim girdilerinin daha yoğun ve çoğu zaman dikkatsizce kullanılmasına yol açmıştır. Çevreye atıkların sorumsuzca bırakılması, hızlı kentleşme ve nüfus artışı, bu gelişmelerin yıkıcı etkilerini önemli ölçüde artırmıştır. Son yıllarda, küresel kamuoyu ve karar vericiler arasında artan farkındalık, küresel ısınma ve iklim değişikliğinin etkilerine yönelik araştırmaların, değerlendirmelerin ve analizlerin artmasına neden olmuştur. İklim değişikliği, günümüz yaşam standartlarını ve insanlığın uzun vadeli geleceğini tehdit eden en kritik sorunlardan biri olarak kabul edilmektedir. Doğal afetlerin sıklığı ve şiddetindeki artış, tarım ürünleri desenlerinde ve sektörel verimliliklerdeki değişiklikler, yüzey ve yeraltı su kaynaklarının kullanılabilirliğindeki değişimler gibi sonuçlar, iklim değişikliğinin küresel etkilerini açıkça ortaya koymaktadır. Bazı bölgeler kısa vadede olumlu etkiler yaşasa da genel küresel etki ağırlıklı olarak olumsuzdur.

Sıcaklık ve yağış iklim değişikliğini değerlendirmek için kullanılan iki temel göstergedir. Bu değişkenlerin uzun dönemli analizleri bir bölgede iklim değişikliğinin varlığını ortaya koyabilmektedir. Sıcaklık ve yağış serilerindeki yapısal kırılmalar, iklimle ilgili değişikliklerin göstergesi olarak yorumlanmaktadır.

Türkiye çeşitli coğrafi özellikleri ve geçiş iklim bölgeleri nedeniyle iklim değişikliğinin etkilerine karşı oldukça hassastır. Yağış ve sıcaklıktaki bölgesel değişiklik kalıplarını anlamak, uyum stratejileri geliştirmek için kritik öneme sahiptir. Her ne kadar konu ile ilgili ulusal düzeyde çalışmalar artmış olsa da bölgesel ölçekte sağlam ekonometrik teknikler kullanan ampirik araştırmalar sınırlı kalmıştır. Bu çalışma, Türkiye’nin Düzey 2 bölgelerindeki iklim değişikliğinin varlığını, sıcaklık ve yağış eğilimlerinde çoklu yapısal kırılma analizi yoluyla incelemek suretiyle bu boşluğu doldurmayı amaçlamaktadır.

Çalışma, Meteoroloji Genel Müdürlüğü’nden elde edilen 1950-2021 dönemini kapsayan 56 istasyondan alınan aylık ortalama sıcaklık ve yağış verilerini kullanmıştır. Eksik veriye sahip istasyonlar, yıllık ortalamalar hesaplanırken dahil edilmemiştir. Her istasyonun ait olduğu Düzey 2 bölgesi belirlendikten sonra her bölge için 72 yıllık zaman serileri oluşturulmuştur. Örnek büyüklüğünü artırmak ve analizin sağlamlığını güçlendirmek için, Haziran’dan sonraki Haziran’a kadar olan 12 aylık ortalamalar da hesaplanmış ve bu iki set birleştirilerek her bölge için 144 gözlem içeren zaman serileri oluşturulmuştur.

Yapısal kırılma analizi için bilinmeyen kırılma tarihlerini tespit etmeyi amaçlayan Bai-Perron testi kullanılmıştır. Analizler, EViews yazılımı kullanılarak her bölge için ayrı ayrı gerçekleştirilmiştir. Sıcaklık ve yağış, bağımlı değişkenler olarak alınmış ve sabit bir bağımsız değişkenle en küçük kareler yöntemiyle iki ayrı denklem tahmin edilmiştir. Hatalardaki seri korelasyonu hesaba katmak için, ikinci dereceden spektral çekirdek tabanlı heteroskedastisite ve otokorelasyon tutarlı (HAC) kovaryans

spesifikasyonu uygulanmış, ön-beyazlatma işlemi için sabit bir dönemlik gecikme belirlenmiştir. Kırılmaların varlığı, supF testi ile tespit edilmiş ve kırılma sayısı ile zamanlaması, sıralı supF(1+1/l) testi ile belirlenmiştir.

Yapılan analizler neticesinde TRA1 bölgesi (Erzurum, Erzincan, Bayburt) hariç, 26 Düzey 2 bölgesinin 25'inde sıcaklıkta yapısal kırılmalar tespit edilmiştir. Kırılmaların çoğu 1990'lar ve 2000'lerin başında gerçekleşmiştir. Tüm bölgelerde kırılma sonrası sıcaklıklar artmıştır. En büyük sıcaklık artışı TRB2 bölgesinde (Van, Muş, Bitlis, Hakkari) gözlenirken, en küçük artış TR81 bölgesinde (Zonguldak, Karabük, Bartın) kaydedilmiştir. Doğu Anadolu ve Trakya'da sıcaklık artışları daha belirgin olmuş, kıyı bölgelerinde (Adana ve Mersin hariç) daha küçük değişimler görülmüştür. Karadeniz Bölgesi nispeten ılımlı sıcaklık artışları sergilemiştir. Marmara Bölgesi'nde artış 1°C'yi aşarken, Akdeniz Bölgesi'nde yalnızca Adana-Mersin alt bölgesinde bu seviye geçilmiştir. İç Anadolu'da Konya-Karaman bölümü hariç sıcaklık artışı 1°C'yi aşmıştır. Doğu ve Güneydoğu Anadolu'da da benzer şekilde çoğu bölgede artış 1°C'yi geçmiştir.

Yağış verilerine Bai-Perron testi uygulandığında yapısal kırılma tespit edilmemiştir. Ancak, sıcaklık kırılma yılları referans alındığında, bölgelerin bazılarının yağış desenlerinde istatistiksel olarak anlamlı değişimler gözlenmiştir. Batı Marmara, Ege, Akdeniz, Doğu Anadolu ve Güneydoğu Anadolu bölgelerinde yağış seviyeleri azalırken, Doğu Marmara, İç Anadolu ve Karadeniz bölgelerinde artışlar gözlenmiştir. t-testi sonuçlarına göre, altı bölgede yağış değişimleri istatistiksel olarak anlamlı bulunmuştur: Orta ve Doğu Karadeniz bölgeleri ile Malatya alt bölgesi (Malatya, Elazığ, Bingöl, Tunceli) %90 güven düzeyinde; Ağrı alt bölgesi (Ağrı, Iğdır, Ardahan, Kars) ve Mardin alt bölgesi (Mardin, Batman, Şırnak, Siirt) %95 güven düzeyinde anlamlı değişimler göstermiştir.

Sıcaklık değişimi ile kentleşme ve sanayileşme arasındaki ilişki, en küçük kareler (OLS) yöntemiyle iki ayrı regresyon denklemi kullanılarak incelenmiştir. Bağımlı değişken, kırılma öncesi ve sonrası dönemler arasındaki ortalama sıcaklık farkı olarak tanımlanmıştır. Kentleşme ve sanayileşme oranları ise bağımsız değişkenlerdir. Bulgular, kentleşme oranının sıcaklık değişimi ile %90 güven düzeyinde istatistiksel olarak anlamlı ve pozitif bir ilişkiye sahip olduğunu göstermektedir. Daha yüksek kentleşme oranına sahip bölgeler, daha belirgin sıcaklık artışları yaşamıştır. Buna karşılık, sanayileşme oranları ile sıcaklık değişimi arasında istatistiksel olarak anlamlı bir ilişki bulunmamıştır.

Sıcaklık ve yağış rejimlerindeki değişimler, tarım, enerji üretimi, inşaat, turizm ve kamu hizmetleri gibi ekonomik sektörleri etkileyebileceği değerlendirilmektedir. Artan sıcaklıklar ve değişen yağış kalıpları, kuraklık, orman yangınları, sel ve taşkın risklerini artırabilecektir. Bu nedenle, sulama sistemleri, kentsel gelişim ve afet hazırlık stratejileri gibi alanlarda iklim değişikliği projeksiyonlarına dayalı planlamalar kritik önemi haizdir. Gelecek araştırmalar, aylık ekstrem değerlere odaklanarak veya sosyoekonomik değişkenleri (ör. kentleşme, nüfus yoğunluğu) entegre ederek, hava olaylarının ekonomik sektörler üzerindeki etkilerini daha iyi değerlendirebilecektir.