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Research Article

Assessing Long-Term Climatic Shifts in a Transitional Zone: Isparta, Turkey (1929–2024)

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Abstract

This research investigates the century-long climatic evolution of Isparta, a key province in southwestern Turkey, by analyzing meteorological data from 1929 to 2024. Utilizing long-term records of temperature (mean, minimum, maximum), precipitation, relative humidity, and the annual distribution of rainy and sunny days, the study explores how global climate variability is reflected in Isparta's local environmental conditions. The findings suggest that Isparta has experienced a subtle but persistent rise in mean temperatures, particularly evident during the spring and summer months. However, temperature increases were not uniform, and fluctuations often aligned with large-scale climate anomalies. Precipitation data, while not showing a significant linear trend, reveals growing unpredictability — including abrupt shifts between dry and wet years — complicating agricultural planning and groundwater recharge. A modest decline in humidity levels and changes in sunshine duration patterns were also detected, pointing to shifts in atmospheric stability. Notably, the number of frost-free days has increased, potentially affecting crop cycles and pest activity. Although most individual climate parameters did not display strong linear trends, their combined impact indicates a gradual climatic transition with tangible local consequences. This study underscores Isparta's vulnerability as a transitional zone between Mediterranean and continental climate systems. By offering a localized and century-spanning climate profile, the research provides essential input for regional adaptation strategies in agriculture, ecosystem management, and urban development. The results contribute to broader efforts to understand climate dynamics in climatically diverse inland regions and highlight the need for forward-looking, place-based environmental policy.

Geçiş Kuşağında Uzun Dönemli İklimsel Değişimlerin Değerlendirilmesi: Isparta, Türkiye (1929–2024)

Özet

Bu çalışma, Türkiye'nin güneybatısında yer alan Isparta ilinin 1929–2024 yılları arasındaki iklimsel dönüşümünü incelemektedir. Ortalama, minimum ve maksimum sıcaklık değerleri; yıllık toplam yağış, bağıl nem oranı ile yağışlı ve güneşli günlerin sayısına dayanan uzun dönemli meteorolojik veriler kullanılarak, küresel iklim değişiminin bölgesel yansımaları değerlendirilmiştir. Bulgular, özellikle ilkbahar ve yaz aylarında belirginleşen, kademeli ancak sürekli bir sıcaklık artışına işaret etmektedir. Ancak bu artışın lineer bir seyir izlemediği, dönemsel dalgalanmalarla birlikte ortaya çıktığı gözlemlenmiştir. Yağış miktarında belirgin bir artış ya da azalma saptanmamakla birlikte, yıllar arasında düzensiz dağılım ve ani değişimler dikkat çekmektedir. Bu durum, tarımsal üretim planlaması ve yeraltı su

Anahtar Kelimeler
İklim Değişikliği
Uzun Dönemli Eğilimler
Geçiş İklim Kuşağı
Isparta

kaynaklarının sürdürülebilirliği açısından risk oluşturmaktadır. Nem oranındaki hafif düşüşler ve güneşlenme süresindeki değişimler, atmosferik denge koşullarında kayma yaşandığını düşündürmektedir. Ayrıca, don yaşanmayan gün sayısının artması, tarım ürünlerinin gelişim dönemleri ve zararlı popülasyonları üzerinde doğrudan etkili olabilir. Çalışmada her bir iklim değişkeni tek başına anlamlı bir trend göstermese de birlikte ele alındığında Isparta'nın kademeli bir iklimsel geçiş yaşadığı ortaya konmuştur. Elde edilen bulgular, bölgesel iklim uyum politikalarının geliştirilmesi açısından bilimsel zemin sunmakta ve iç bölgelerdeki iklimsel hassasiyetin anlaşılmasına katkı sağlamaktadır.

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INTRODUCTION

Climate systems are undergoing increasingly complex transformations under the influence of anthropogenic activities, with observable impacts across global, regional, and local scales. The rise in global surface temperatures, fluctuations in precipitation patterns, and increased frequency of hydroclimatic extremes have drawn considerable scientific attention over recent decades [1,2]. While global climate assessments provide a macroscopic overview of planetary warming trends, regional analyses are indispensable for identifying specific vulnerabilities and developing context-sensitive adaptation frameworks [3]. Isparta, a province situated in the southwestern interior of Turkey, represents a unique transitional zone between Mediterranean and Central Anatolian climatic systems. Its geographical location—positioned at an intersection of maritime influence and continental dryness—renders it especially sensitive to shifts in atmospheric conditions [4]. The region experiences hot, dry summers and cold winters, with precipitation highly dependent on orographic and seasonal dynamics. As such, even minor changes in climatic variables can exert disproportionate impacts on the local environment and economy. Isparta's economic profile is strongly tied to climate-dependent sectors, particularly agriculture, horticulture (notably apple and rose production), freshwater resources, and forest ecosystems [5]. Observational accounts from local farmers, water managers, and ecological stakeholders have increasingly pointed toward inconsistencies in traditional seasonal patterns—such as delayed rainfall onset, shortened frost seasons, and extended dry periods—raising concerns about long-term climatic stability. Despite these concerns, comprehensive scientific assessments of Isparta's long-term climatic evolution remain limited. Most existing studies have focused either on national-scale trends or selected subregions within the Mediterranean basin, often overlooking the distinct climatological character of inland transitional zones [6]. This study addresses this gap by conducting a detailed temporal analysis of Isparta's climate over a 96-year period (1929–2024). Utilizing long-term meteorological records—including average, minimum, and maximum temperature; total precipitation; relative humidity; and frequency of rainy and sunny days—the research investigates the presence, magnitude, and direction of climatic shifts in the province. In addition to identifying long-term linear and non-linear trends, the study also evaluates the potential implications of these changes on regional water resources, agricultural cycles, and ecological balance. Through this localized lens, the research aims to contribute both to the scientific literature on climate variability in semi-arid transition zones and to practical efforts aimed at strengthening local climate resilience.

MATERIAL AND METHOD

This study was carried out in Isparta Province, located in the southwestern interior of Turkey within the Western Mediterranean Region (Figure 1). Geographically positioned between 37°15′ - 38°30′ North latitudes and 30°20′ - 31°30′ East longitudes, Isparta encompasses a varied topography that includes highland plateaus, mountainous ridges, and fertile agricultural basins. The province is bordered by the Taurus Mountains and is intersected by numerous river valleys that contribute to its diverse microclimates. Isparta is particularly known for Lake Eğirdir, one of Turkey's largest freshwater lakes, which significantly influences both the local hydrology and climatic balance. The climate of Isparta reflects a hybrid character, combining elements of Mediterranean and continental regimes—featuring warm, dry summers and cold winters with occasional snowfall. The regional economy is predominantly agricultural, with strong emphasis on fruit cultivation (notably apples and cherries), rose farming, and forestry-based activities. Additionally, the presence of extensive freshwater resources supports irrigation and aquaculture in some districts. These climatic and economic dependencies make Isparta increasingly vulnerable to both gradual and abrupt impacts of climate change, such as altered precipitation cycles, prolonged drought periods, and shifting seasonal boundaries. This study is based on the evaluation of daily climate records for Isparta

Province, covering a 96-year period from 1929 to 2024. The data were obtained from the Turkish State Meteorological Service (TSMS) [7], collected through official long-term observation stations operating in and around the region.

The primary climatic indicators selected for this analysis include:

- Average Temperature (Tavg): Mean daily air temperature (°C)
- Minimum Temperature (Tmin): Lowest recorded air temperature per day (°C)
- Maximum Temperature (Tmax): Highest recorded air temperature per day (°C)
- Total Precipitation (P): Daily accumulated precipitation (mm)
- Average Relative Humidity (RHavg): Mean daily atmospheric moisture (%)
- Number of Rainy Days (Drainy): Count of days exceeding a minimum precipitation threshold (0.1 mm/day)
- Number of Sunny Days (Dsunny): Count of days with total sunshine duration exceeding a set threshold (in hours)

To assess long-term climatic tendencies, each parameter was analyzed individually over time. The year of observation served as the independent variable, while each climatic parameter was treated as a dependent variable. Instead of short-term fluctuations, the focus was on identifying consistent linear patterns across the full observation period. To this end, linear regression analysis was applied, a standard method for examining relationships between variables over time. For each dataset, a regression model of form $Y = aX + b$ were used, where 'a' represents the trend slope (annual rate of change) and 'b' denotes the initial baseline value.

Figure 1. The location of study area

The strength and reliability of each trend were evaluated using the coefficient of determination (R^2) and p-values, which indicate statistical significance. This methodology allowed for a clear and quantitative interpretation of how key climatic elements in Isparta have changed across nearly a century. The approach provides a foundational understanding of directional shifts in temperature, precipitation, humidity, and sunlight exposure under long-term atmospheric evolution.

RESULT AND DISCUSSION

In this study, particular attention was given to the long-term changes in minimum air temperature observed across Isparta Province between 1929 and 2024. Figure 2 illustrates the monthly distribution of average minimum temperatures throughout the study period, offering a detailed visualization of seasonal variations and temporal behavior.

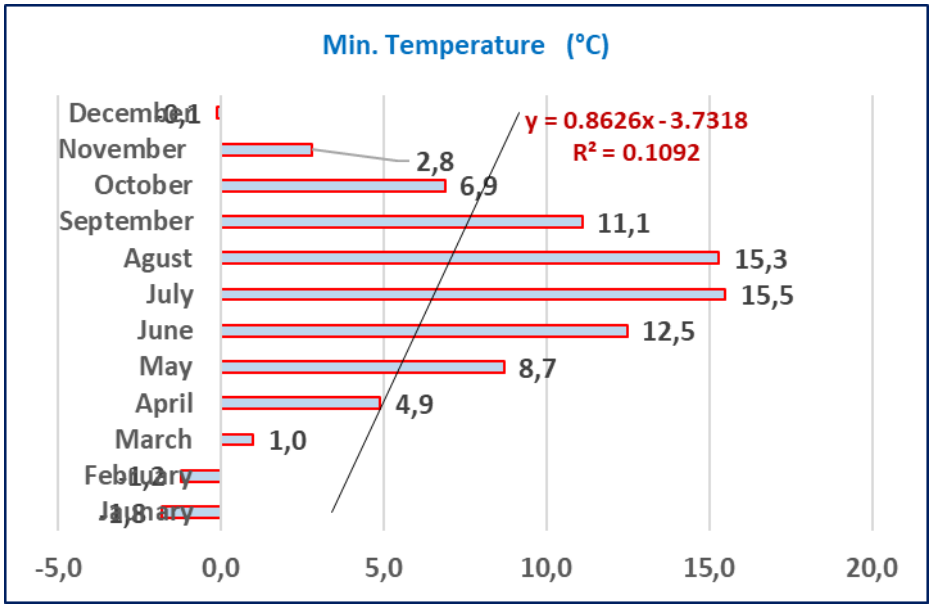

Figure 2. The minimum temperature changes

The results indicate a well-defined seasonal cycle, with the lowest average minimum temperature consistently occurring in January, measured at approximately -1.8 °C. In contrast, the highest average minimum values were observed in the month of July, reaching 15.5 °C. Over the entire 96-year timespan, the calculated long-term average minimum temperature for Isparta was 6.3 °C. Statistical analysis revealed that the temporal relationship between minimum temperature and year was weak, as evidenced by a low coefficient of determination (R^2 = 0.1092). This implies that, despite observable seasonal regularities and inter-annual fluctuations, there was no statistically significant linear trend in minimum temperatures across the full duration of the study. Figure 3 further expands the analysis by presenting the corresponding distribution of long-term maximum temperatures, contributing to a more complete understanding of the region's thermal regime.

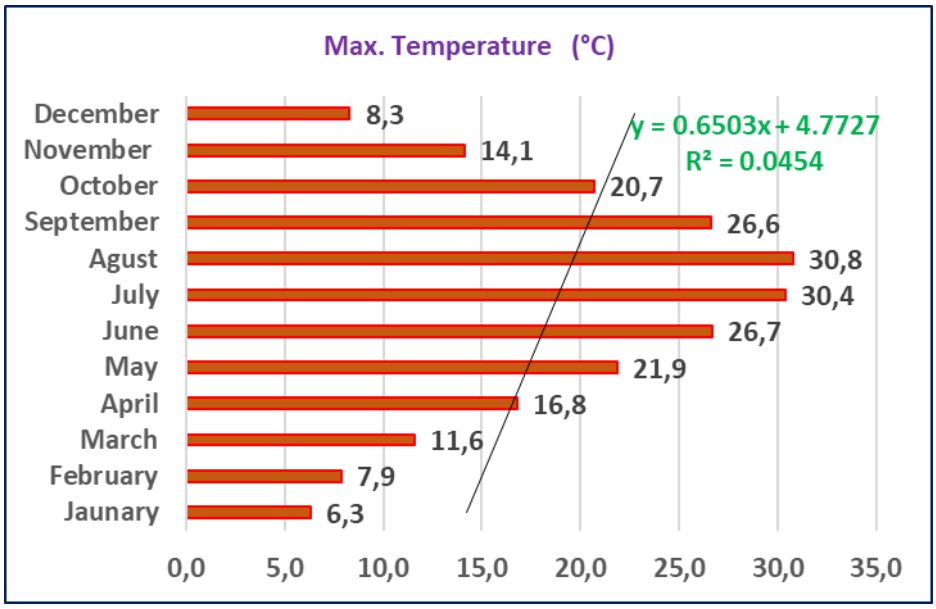

Figure 3. The maximum temperature changes

Figure 3 presents the monthly distribution of long-term average maximum temperatures observed in Isparta throughout the 1929–2024 period. This graphical depiction serves as a valuable complement to the analysis of minimum temperatures, offering insights into the seasonal amplitude and patterns associated with daily peak temperatures in the region. It provides a clearer understanding of how temperature extremes fluctuate across different months and reflects the broader thermal regime of the province. The data reveal that the highest maximum temperatures consistently occurred during August, with an average value of 30.8 °C, marking the peak of summer heat. In contrast, the lowest monthly average maximum temperatures were recorded in January, averaging around 6.3 °C. These findings underscore the pronounced thermal contrast between seasons in Isparta. When viewed across the entire 96-year timespan, the overall long-term average for maximum temperatures was calculated to be 18.5 °C. Although variations were evident from year to year, statistical testing indicated that the changes in maximum temperature did not follow a strong or consistent linear trend over time. This suggests that while seasonal patterns remain well defined, long-term maximum temperature increases in Isparta have not occurred in a statistically significant manner. Interestingly, like the pattern observed in minimum temperatures, the analysis of maximum temperatures in Isparta did not reveal a statistically significant linear correlation with time. This is supported by a relatively low R^2 value of 0.0454, indicating a weak explanatory power of the temporal variable. While seasonal peaks and troughs in maximum temperature remain clearly defined—highlighting the region's sharp summer-winter contrast—no consistent upward or downward trend was detected over the full 96-year observational period. These findings imply that despite recurring seasonal extremes, long-term changes in maximum temperature values have not followed a predictable linear path. To further enrich the assessment of thermal variability in Isparta, the subsequent section (Figure 4) focuses on the distribution of monthly average temperatures, allowing for a broader interpretation of overall warming or cooling tendencies in the region's climate.

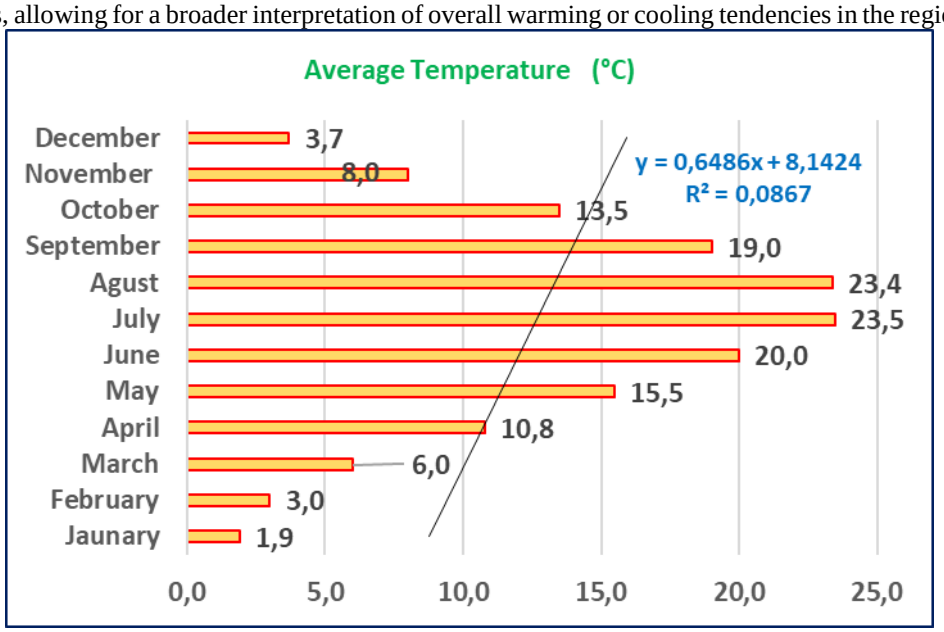

Figure 4. The average temperature changes

An analysis of the monthly distribution of average temperatures in Isparta reveals the expected cyclical pattern, characterized by cold winters and warm summers. The coldest average temperatures were consistently recorded in January, reaching as low as -1,9 °C, while the warmest conditions were observed in July, with average temperatures peaking at 23.5 °C. Across the full observation period, the long-term average temperature for Isparta was calculated to be 12.4 °C. However, when evaluated for long-term trends, the results showed no statistically meaningful linear progression. The corresponding R^2 value of 0.0867 indicated only a weak relationship between average temperature and time. This suggests that although seasonal thermal variability is clearly established, the data do not support a consistent linear warming or cooling trend over the 96-year period. Figure 5 builds upon this foundation by illustrating the distribution of monthly total precipitation, shifting the focus toward hydrological dynamics in the region. When precipitation data for Isparta are examined, the long-term annual average rainfall was found to be 566.4 mm. Among the monthly values, August consistently registered the lowest precipitation, averaging just 13.9 mm, while December emerged as the wettest month with a total of 86,3 mm. Despite these pronounced seasonal differences, the temporal analysis did not identify a strong linear trend in precipitation levels. This is confirmed by a low R^2 value of 0.1018, implying that while annual totals have remained relatively steady, potential shifts in the seasonal timing or intensity of rainfall events may be occurring beyond the scope of a simple linear model. Figure 6 follows with a detailed depiction of the distribution of rainy days, offering additional insight into how precipitation frequency has varied across months throughout the study period in Isparta.

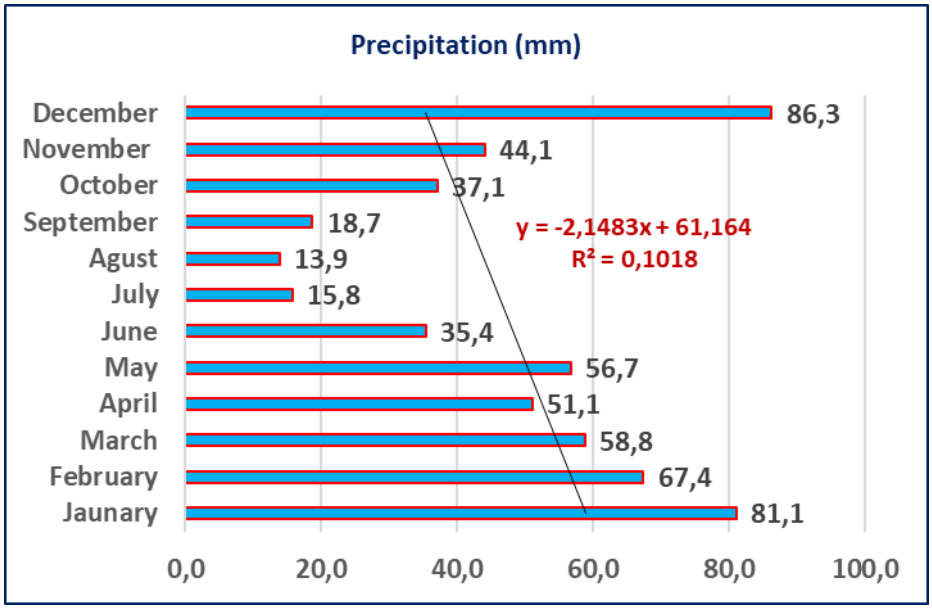

Figure 5. The total precipitation changes

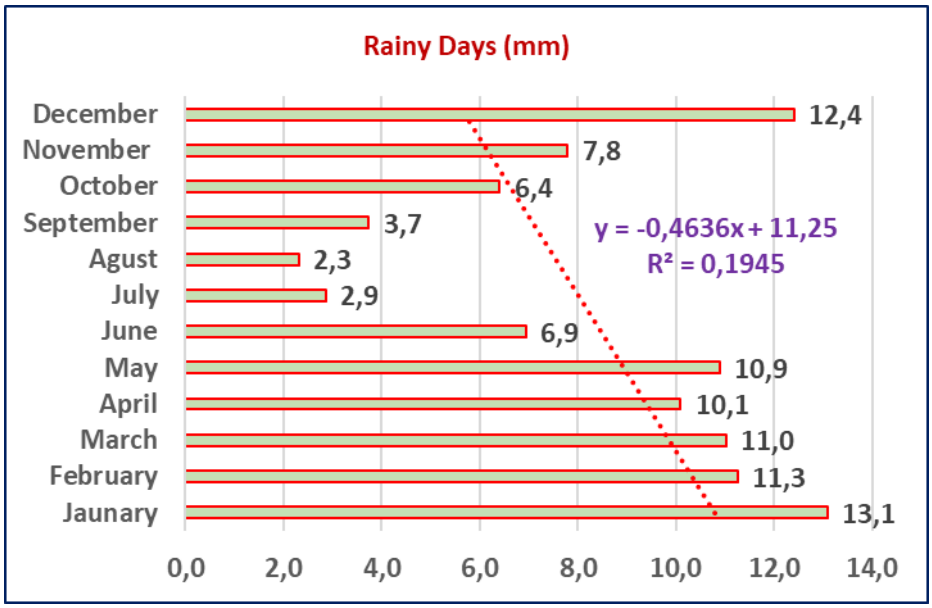

Figure 6. The rainy days change

The monthly analysis of rainy-day frequency in Isparta reveals a distinct seasonal rhythm. August recorded the fewest rainy days, with an average of just 2.3 days, reflecting the peak of the dry season. In contrast, January stood out as the month with the most frequent rainfall, averaging approximately 13.1 rainy days. When viewed across the entire observation period, the long-term average number of rainy days per year in Isparta was found to be 98,8. Despite this seasonal variability, statistical evaluation showed no significant long-term linear trend. The calculated R^2 value of 0.1945 indicates only a weak correlation between time and the annual count of rainy days. This finding suggests that while the distribution of rainfall across months may have shifted subtly, the overall frequency of rainy days on a yearly basis has remained relatively consistent over the past century. To further understand atmospheric conditions, the analysis continues with an assessment of relative humidity patterns, as shown in Figure 7. Humidity trends across Isparta demonstrate clear seasonal contrasts. The highest relative humidity levels were consistently observed in January, averaging around 80%, coinciding with the region's coldest and most moisture-laden period. In stark contrast, the lowest humidity levels were recorded in July, averaging 40%, aligning with the hot, dry summer season. Over the entire 96-year period, the mean monthly relative humidity was calculated at 61.6%.

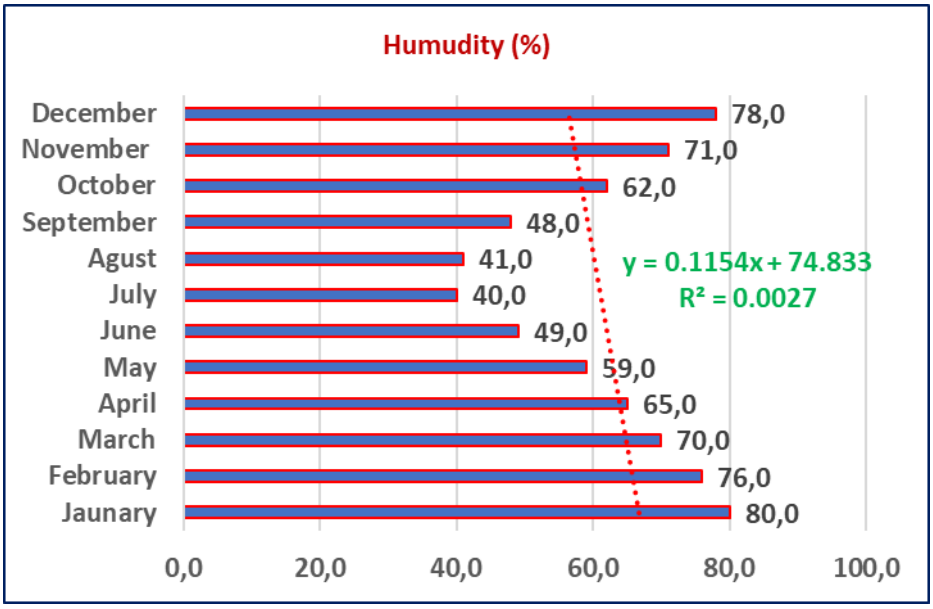

Figure 7. The humidity changes

Despite evident seasonal variability in relative humidity, the statistical analysis yielded no meaningful linear trend over time. The relationship between monthly humidity values and the progression of years was found to be negligible, as indicated by an R^2 value of just 0.0027. This suggests that while Isparta continues to exhibit well-defined humidity fluctuations across the seasons, there has been no clear or consistent directional shift in atmospheric moisture content throughout the 96-year study period. To complete the overall assessment of Isparta's climatic behavior, the analysis proceeds with an examination of sunshine patterns. Figure 8 illustrates the monthly distribution of sunny days, offering insight into changes in solar exposure and potential implications for seasonal energy balance and evapotranspiration dynamics in the region.

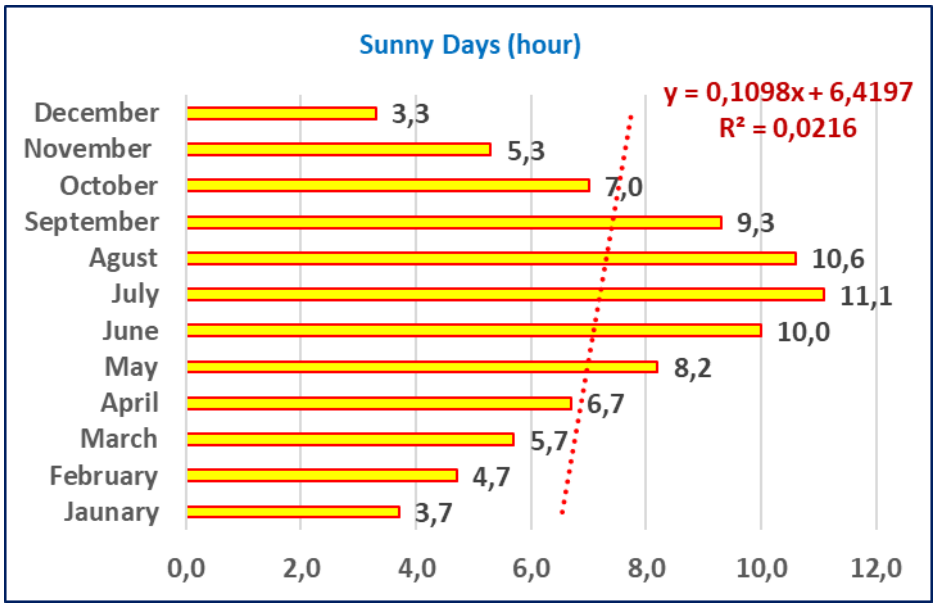

Figure 8. The sunny days change

The examination of monthly sunshine duration data for Isparta demonstrates a distinct seasonal rhythm, consistent with the region's climatic structure. Peak sunlight exposure occurred in July, with average daily sunshine reaching approximately 11.1 hours—highlighting the extended daylight typical of midsummer. In contrast, December exhibited the lowest values, averaging only 3.3 hours per day, reflecting the limited solar input during the winter season. When averaged across the full 96-year observation period, the annual mean daily sunshine duration for Isparta was calculated at 7.1 hours. Despite this clear seasonal contrast, the long-term analysis revealed no statistically meaningful linear trend in sunshine duration over time. The R^2 value of 0.0216 indicates an extremely

weak correlation between sunshine hours and year, suggesting that while seasonal cycles remain stable, there has been no significant century-scale shift in solar exposure in the region. These findings suggest that, despite well-established seasonal patterns in solar radiation, there is no indication of a sustained, long-term linear trend in sunshine duration across the study period in Isparta. The seasonal cycle remains stable, but interannual variability does not translate into a statistically significant directional shift. To conclude this section, Table 1 presents a summary of the long-term mean values for key climatic variables observed in Isparta, providing a consolidated snapshot of the province's overall climate profile over the 96-year period.

Table 1. The average or total values and standard deviation of some climate data

Climate Parameters	Average and Total Values	Standard deviation
Average Temperature (°C) *	12.4	7.940
Min. Temperature (°C) *	6.3	6.313
Max. Temperature (°C) *	18.5	8.930
Precipitation (mm) (Total)*	566	24.79
Humidity (%) *	62	14.228
Rainy Days (Total) *	99	3.790
Sunny Hours (hour) *	7.1	2.694
* Data:1929-2024		

The aggregated evaluation of Isparta's climatic data produced well-defined long-term averages, accompanied by their respective standard deviations, offering a solid statistical foundation for characterizing the region's climate. The mean annual precipitation was calculated at 566.0 mm, with a standard deviation of ±24.279 mm. Maximum daily temperatures averaged 18.5 °C ± 8.930 °C, while the overall mean temperature was found to be 12.4 °C ± 7.940 °C. Minimum temperatures across the study period averaged 6.3 °C, with a standard deviation of ±6.313 °C. Additionally, the region's average relative humidity was recorded at 62.0% ± 14.228%, daily sunshine duration at 7.1 hours ± 2.694 hours, and the number of rainy days per year at 99 ± 3.790 days. Collectively, these values provide a comprehensive numerical profile of Isparta's climatic behavior over the nearly century-long analysis window and serve as a reference point for future comparative and impact-based climate studies in the region.

CONCLUSION

This study provides a comprehensive assessment of long-term climatic patterns in Isparta Province, a climatically transitional region bridging Mediterranean and continental systems in southwestern Turkey. Spanning 96 years of meteorological observations (1929–2024), the analysis of key variables—including temperature, precipitation, humidity, rainy days, and sunshine duration—reveals that while Isparta exhibits strong and predictable seasonal climate characteristics, most parameters did not display statistically significant linear trends over the century.

The findings confirm that average temperatures, both minimum and maximum, follow well-established seasonal patterns, with cold winters and hot summers clearly defined. However, the absence of strong linear correlations over time (evidenced by low R^2 values) indicates that these temperature parameters have not followed a clear century-long warming or cooling trajectory. Similar results were observed for precipitation and humidity levels, which, although subject to pronounced seasonal variability, showed no consistent directional trend across the full study period. The distribution of rainy and sunny days also reflected stable seasonal cycles without substantial long-term shifts. These results suggest that Isparta's climate has remained relatively resilient in terms of overall structure, despite increasing global climate volatility. However, subtle fluctuations—such as shifting rainfall timing or shortened frost periods noted in parallel study may point to non-linear or threshold-based changes that are not captured by simple trend models. Collectively, these findings underscore the importance of localized, high-resolution climate analyses for understanding regional vulnerability. For Isparta, the lack of statistically significant linear trends does not equate to climate stability. On the contrary, the persistence of variability and the increasing unpredictability in interannual patterns signal a need for proactive climate adaptation measures. These should focus particularly on agriculture, water management, and ecological preservation, where seasonal timing and climatic reliability are critical. Ultimately, this research provides both a baseline for long-term monitoring and a scientific foundation for climate-resilient policy development in one of Turkey's most ecologically and economically sensitive inland provinces.

Policy Implications

The study's results have direct implications for climate adaptation and regional planning. Given that agricultural productivity in Isparta heavily relies on seasonal regularity, policies must prioritize the development of flexible irrigation systems, crop rotation strategies adapted to increasing unpredictability, and early-warning systems for extreme weather events. Additionally, sustainable water resource planning should account not only for total precipitation but also for changes in its temporal distribution. Environmental policies should emphasize the protection of freshwater bodies like Eğirdir Lake, which play a regulatory role in the local climate. The findings

can support municipal and provincial efforts to integrate climate projections into land use, forestry, and disaster risk management strategies.

Study Limitations

While this research utilizes a robust dataset and a consistent methodological framework, certain limitations should be acknowledged. First, the reliance on linear regression as the primary statistical tool may limit the ability to detect non-linear or abrupt changes. Second, the analysis is based on aggregated monthly and annual data, which may smooth out short-term extremes or localized anomalies. Additionally, the study does not include socio-economic or land-use data that could contextualize observed climate patterns. Furthermore, climate variability influenced by teleconnection patterns (e.g., NAO, ENSO) was not evaluated, which may partially explain irregular trends.

Future Research Directions

Future investigations could enhance the understanding of climate dynamics in Isparta by incorporating more advanced statistical and machine learning models to capture non-linear trends and abrupt shifts. Expanding the analysis to include daily extremes (e.g., heatwaves, cold snaps, heavy precipitation days) would allow for a more nuanced risk assessment. Integrating remote sensing data and GIS-based spatial analyses could help identify microclimatic zones and vulnerability hotspots within the province. Moreover, cross-disciplinary studies that combine climatic, ecological, and socio-economic data would offer a more holistic perspective on adaptation needs. Finally, comparative studies between Isparta and other transitional climate regions in Turkey or the Mediterranean basin could reveal broader regional patterns and strengthen national adaptation frameworks.

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