

# Air Temperature Fluctuations in Sarajevo and Climate Projections in the Context of Climate Change

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## Abstract

When discussing climate change, we primarily refer to global warming, that is, the increase in air temperature which directly affects other climatic elements. The Sarajevo meteorological station has a homogeneous series of observations and measurements of this climatic element spanning 136 years (from 1888 to 2024) without interruption, which represents a highly representative period for monitoring changes in air temperature and its fluctuations in the study area. The main characteristic of the thermal regime in the Sarajevo area is warming. The mean annual temperature for the entire instrumental period is 9.8°C, with a linear warming trend of 1.7°C. In addition to the general analysis of air temperature and its fluctuations in Sarajevo over this long-term observational period, special attention will be devoted to projecting this climatic element up to the year 2100 under different climate scenarios.

**Keywords:** climate change; air temperature; climate scenarios; Sarajevo

## Introduction

Climate change represents one of the most important challenges of the modern era faced by human society, significantly affecting natural processes on Earth. Several decades ago, climate change was discussed primarily within the scientific community, whereas today the processes of climate change and the associated natural phenomena are evident to the majority of the global population. It is noticeable that air temperatures are steadily increasing and that predicting weather conditions for any given month of the year has become increasingly difficult (Berdin et al., 2018), all as a result of intensified climate change processes. The Intergovernmental Panel on Climate Change (IPCC) defines climate change as "...any change in

climate over time, whether due to natural variability or as a result of human activity."

The United Nations define climate change as long-term shifts in temperatures and weather patterns. They also emphasize that such changes may result from natural factors (e.g., periodic and secular perturbations of the Earth's orbit around the Sun, Earth's motion, large quantities of aerosols emitted during volcanic eruptions, wildfires, etc.) as well as anthropogenic factors, which have become increasingly pronounced in recent decades (Popović & Vuković, 2019; Hrelja & Drešković, 2025).

Human influence on climate is manifested through various forms of activities and interventions, including deforestation and the expansion of agricultural and urbanized areas. Through the consumption of fossil fuels

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(in energy production, transportation, agriculture, etc.), humans contribute to increased concentrations of carbon dioxide (CO<sub>2</sub>) and other gases in the atmosphere, thereby intensifying the greenhouse effect and consequently global warming. The most important greenhouse gases naturally present in the atmosphere, which absorb longwave terrestrial radiation, include water vapor and carbon dioxide (CO<sub>2</sub>), followed by methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), and ozone (O<sub>3</sub>). Despite internationally defined obligations, atmospheric carbon dioxide concentrations continue to rise and, according to the World Meteorological Organization, reached record levels in 2019, being nearly 150% higher than in 1750 (Hrelja & Drešković, 2025). From this perspective, there is an urgent need to establish and implement mandatory policies aimed at reducing greenhouse gas emissions, particularly in the fossil fuel, waste, and agricultural sectors.

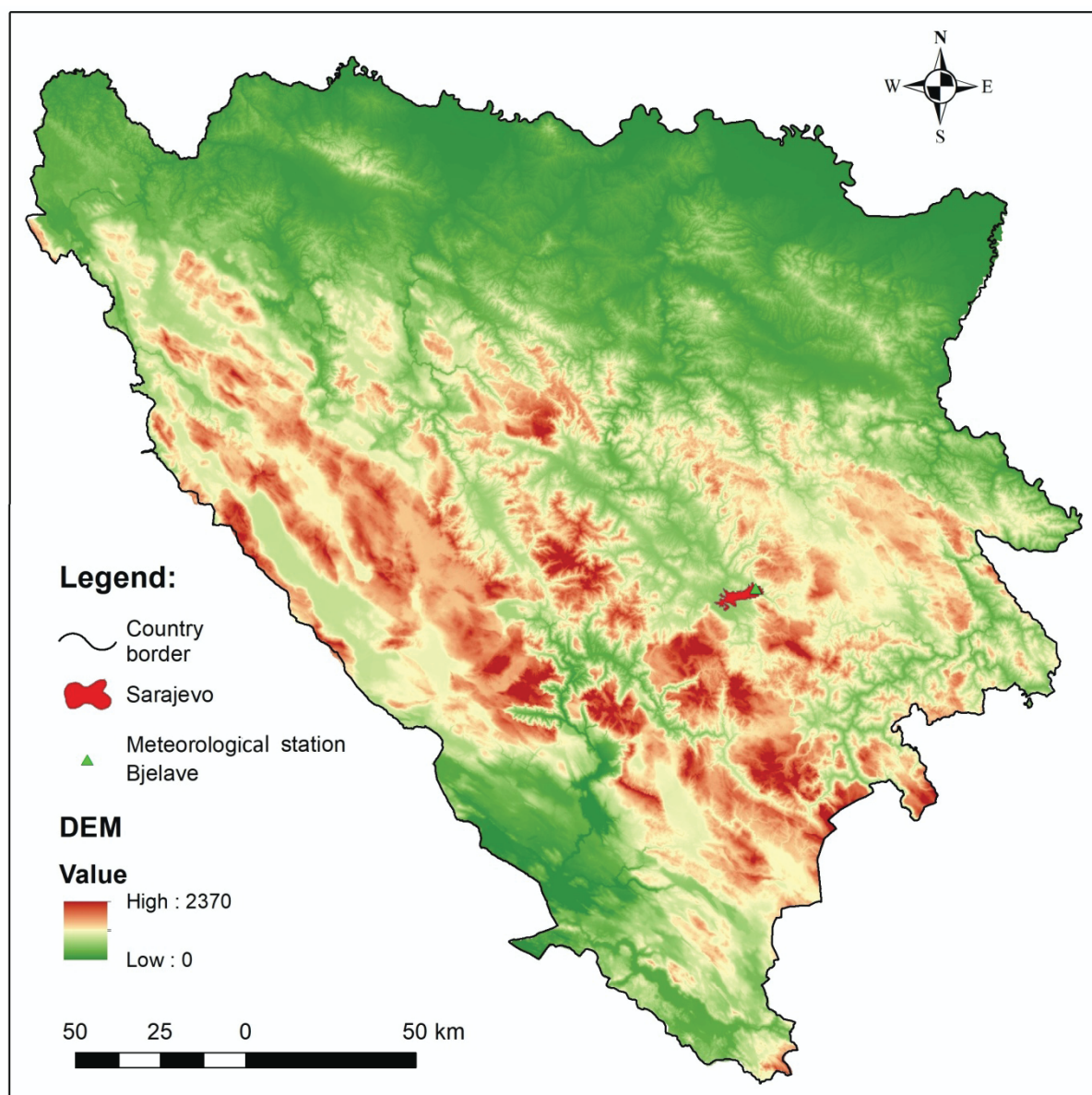
According to meteorological measurements, global temperatures have increased by 1.1 °C compared to the pre-industrial period. The global mean temperature between 2013 and 2023 was 1.19–1.22 °C warmer than the pre-industrial level, making this decade the warmest on record. However, regional differences in temperature increase are evident. Temperatures across the European continent rose even faster during this period, by 2.12–2.19 °C (Drešković & Hrelja, 2025b). Countries that are parties to the United Nations Framework Convention on Climate Change (UNFCCC) have committed to limiting global temperature increase to well below 2 °C above pre-industrial levels, while striving to limit warming to 1.5 °C (Hrelja & Drešković, 2025).

The regional temperature of Southeast Europe increased during the second half of the 20th century. The period 1991–2020 is 0.5–1.0 °C warmer compared to the reference period 1990–1961, and warming will continue in the coming decades (Popov et al., 2018). The average temperature increase in the Western Balkans region is 1.2 °C compared to earlier climatic

periods (Vuković & Vujadinović, 2018). By the end of the 21st century, further warming of between 1.7 and 4.0 °C is expected, depending on the influence of physical-geographical and socio-geographical factors. The Mediterranean region is warming approximately 20% faster than the global average and is considered one of the world's climate change hotspots. The average temperature increase in the Mediterranean has already reached 1.54 °C, and it is estimated to reach 2.2 °C by 2040 relative to the pre-industrial period. Consequently, Mediterranean countries are particularly exposed to the negative impacts of climate change (Vitali, 2021).

Regarding changes in precipitation, a generally balanced trend with pronounced regional variations is observed. In some areas, particularly northern regions, a slight increase in precipitation may occur, while southern areas, especially coastal zones, are expected to experience a decrease, leading to more frequent droughts, particularly during the summer months (Vuković & Vujadinović, 2018).

Bosnia and Herzegovina is located in the central part of the northern temperate climate zone and covers an area of 51,209 km<sup>2</sup>, of which 51,179 km<sup>2</sup> is land and 12.2 km<sup>2</sup> is marine area (Drešković & Mirić, 2017a). The general climatic characteristics of Bosnia and Herzegovina are determined by the interaction between climatic factors and the quantitative and qualitative values of climatic elements. The most important climatic modifier is the country's orographic structure. The peripannonian region of Bosnia is widely open to the intrusion of cold continental air masses from the north and northeast, which penetrate deep into the mountainous-basin interior along the valleys of major rivers (Drina, Bosna, Vrbas, Sana, and Una). Nevertheless, despite the openness of the Pannonian Basin, the influence of these air masses is significantly reduced by the Alpine, Carpathian, and Balkan mountain systems surrounding the area from the north, northeast, and east (Drešković & Mirić, 2017a).



**Figure 1.** Geographical location of Sarajevo

*Source: Authors, based on GIS data from the Department of Geography, University of Sarajevo.*

At regional and local scales, orographic characteristics represent the most significant climatic factor. The Sarajevo Basin is located in an intramontane depression, with an average elevation of approximately 500 m, between the Bjelašnica and Igman massifs to the southwest and low- to mid-altitude mountainous terrain to the northeast. These physical-geographical characteristics, together with socio-geographical processes such as urbanization, land-cover changes, and the impact of construction on urban ventilation corridors, significantly influence the characteristics of the local climate in Sarajevo.

Research results show that a significant warming trend is present across the entire territory of Bosnia and Herzegovina. Both maximum and minimum

temperatures have increased over the observed period. The rise in warm temperature extremes is particularly pronounced, while cold extremes show a decreasing trend (Popov et al., 2018). In Bosnia and Herzegovina, climate change has intensified over the past three decades (1995–2025), manifested through rising air temperatures, altered precipitation patterns, more frequent heatwaves, and changes in climate indices (Trbić et al., 2026). Research indicates that temperature increases in some of the largest urban centers in Bosnia and Herzegovina have exceeded the 2 °C threshold, accompanied by significant changes in precipitation regimes (Trbić, 2024). Based on data from the Bjelave meteorological station – the oldest in Bosnia and Herzegovina, with a homogeneous series of observa-

tions dating from 1888 to the present—the recorded temperature increase exceeds 1.5 °C. The dominant feature of the thermo-pluviometric regime of Bosnia and Herzegovina is warming, or humid stagnation, as linear trends in air temperature and precipitation amounts are positive (1.7 °C and 14 mm, respectively) (Drešković & Hrelja, 2025a). Climate models and projections for Bosnia and Herzegovina until the end of the 21st century indicate a rapid increase in air temperature, along with major changes in the precipitation regime, including an increase in intense rainfall events that contribute to fluvial, urban, and flash floods, as well as an increase in the number of dry days, which affects the occurrence of droughts and forest fires (Trbić, 2024). Furthermore, research results show that climate warming in Bosnia and Herzegovina is accompanied by a significant increase in the frequency and intensity of extreme heat events, including heatwaves (Trbić et al., 2022).

As a result of intensified climate change, high temperatures, increased air humidity, uneven precipitation distribution, and other associated phenomena contribute to making certain parts of the Earth increasingly unsuitable for human habitation. According to some estimates, more than 600 million people are directly or indirectly affected by the consequences of climate change (Schaeffer, 2025). Vulnerability assessments at the national level in Bosnia and Herzegovina indicate that the most sensitive sectors include agriculture, water resources (particularly droughts and floods), forestry and biodiversity, human health, and tourism (Žurovec et al., 2017; Ministry of Foreign Trade and Economic Relations of Bosnia and Herzegovina, 2020; UNDP, 2022).

In this context, it is essential to establish response plans and early warning systems to mitigate the negative spatial effects caused by climate change, with the aim of reducing damage to natural and socio-economic assets and minimizing human casualties. Scientific research plays a crucial role in climate change modeling. Through observation and analysis of climatic data, it is possible to derive relevant indicators of present climatic conditions, reconstruct past climate variability, and project future changes in climatic elements (Popović & Vuković, 2019).

Climate change assessments employ scenarios based on five socio-economic development pathways (Shared Socioeconomic Pathways – SSPs) and projected greenhouse gas concentrations in the atmosphere. According to the IPCC (2021), the only scenarios that project temperature increases remaining within the limits set by the Paris Agreement are those with projected warming of 1.0–1.8 °C, as well as scenarios with temperature ranges of 1.3–2.4 °C by the end of the 21st

century compared to pre-industrial levels. These scenarios assume drastic emission reductions in the coming decades, achieving net-zero CO<sub>2</sub> emissions around 2050, followed by net-negative emissions. Without substantial efforts to reduce greenhouse gas emissions, global temperature increases will continue rapidly and may even accelerate. Under the most unfavorable scenario, temperature increases of 3.3–5.7 °C by the end of the 21st century are projected (Hrelja & Drešković, 2025).

The exposure of human society, natural assets, and critical infrastructure—systems essential for societal functioning—has become, and will continue to become, increasingly vulnerable due to the growing frequency of natural hazards driven by intensified climate change. Monitoring key climatic elements and modelling them through multicriteria analyses combined with physical-geographical and socio-geographical spatial factors, alongside the application of modern geoinformatics and artificial intelligence (AI) technologies, methods, and tools, can enhance the resilience of natural and socio-economic systems. These approaches support early risk detection, improved coordination, and more effective planning for climate change adaptation (Schaeffer, 2025). The implementation of such solutions may include predictive maintenance systems, simulations of extreme event scenarios, and automated adaptation and mitigation procedures addressing impacts caused by intensified climate change.

The analysis of climate change in Sarajevo has particular significance, given that the Sarajevo Basin is a true representative of the general climatic characteristics of the mountainous part of Southern Europe. In this regard, it can serve as a valuable complement for completing the overall picture of the scale of climate variability across the wider Western Balkan region.

The meteorological station at Bjelave has a homogeneous series of observations and measurements from 1888 to the present, which is highly representative for studying fluctuations in the main climatic elements, as well as for developing projections of climate change based on them. This research represents a continuation of previous studies on climatic elements and climate change in the territory of Bosnia and Herzegovina (Trbić et al., 2026; Drešković & Hrelja, 2025a; Drešković & Hrelja, 2025b; Drešković & Hrelja, 2025c; Trbić, 2024; Trbić et al., 2022; Popov et al., 2018). Previous research in the Sarajevo area has mainly focused on presenting the state of basic meteorological elements, namely temperature and precipitation. Earlier studies (Drešković & Hrelja, 2025a; Blažević et al., 2025; Drešković & Mirić, 2017b) addressed fluctuations in temperature and precipitation,

but were limited to shorter historical periods for which climatological data were available. However, this area is still insufficiently explored in terms of climate change trends. The main objective of this paper is to develop climate scenarios of annual air temperature change in the Sarajevo area based on IPCC climate scenarios. Given the existing lack of knowledge about climate change at the level of Sarajevo, as well as Bosnia and Herzegovina as a whole, the aim of this study is to provide baseline assumptions about future air temperature change scenarios in this area. This research can be of great importance for the wider community, as it may serve as a foundation for establishing timely plans for adaptation to climate change and related extreme events, with the goal of reducing their impacts on natural resources and material assets.

## Data and Methods

The methodological framework for conducting the research was defined in accordance with the objectives and tasks of the study, which focus on analysing air temperature fluctuations and climate projections in the context of climate change in Bosnia and Herzegovina. In this context, the primary objective was to present changes in one of the key meteorological indicators—the thermal regime—during the recent climatic period and to model this climatic element up to the year 2100 under different climate scenarios.

The defined research tasks were carried out through several phases:

Phase 1: Collection of meteorological air temperature data for Sarajevo for the period from 1888 to 2024 from official statistical sources of the Federal Hydrometeorological Institute of Bosnia and Herzegovina (FHMZBiH, 2024).

These data were used to analyse changes in air temperature over the period 1888–2024 and to determine fluctuations of this meteorological element within the temporal framework from the establishment of the meteorological station network in Bosnia and Herzegovina to the present.

Phase 2: Analysis of air temperature changes in the study area under three different IPCC climate

scenarios: SSP1-2.6 (low emissions, ambitious climate policies), SSP2-4.5 (moderate emissions, intermediate scenario), and SSP5-8.5 (the most pessimistic scenario, very high emissions). These three scenarios were selected to illustrate projected air temperature changes up to 2100 under conditions of very low, moderate, and high greenhouse gas emissions.

According to the IPCC Interactive Atlas (Regional Information – Advanced) and based on CMIP6 projection models, the aforementioned scenarios (SSP1-2.6, SSP2-4.5, and SSP5-8.5—more detailed scenarios from the CMIP6 era that integrate socio-economic factors to provide robust climate projections) were analyzed for three time periods: 2021–2040 (near term), 2041–2060 (medium term), and 2081–2100 (long term), for the Mediterranean region, to which Sarajevo spatially belongs according to this projection.

The Mediterranean region was selected as the reference spatial framework for climate projections because, according to the classification of the Intergovernmental Panel on Climate Change (IPCC) and the IPCC Interactive Atlas, Bosnia and Herzegovina, including Sarajevo, belongs to the Mediterranean region. Although Sarajevo is geographically located in the interior of the Balkan Peninsula, its climatic characteristics represent a transitional type between continental and Mediterranean influences. While Sarajevo is not a typical Mediterranean area, its climate is significantly affected by Mediterranean processes, particularly in terms of seasonal warming and the distribution of precipitation. According to the Interactive Atlas, the region of Western and Central Europe, in comparison to the Mediterranean region, shows temperature values that are higher by approximately 0.2°C across all analyzed scenarios and periods. For this reason, the Mediterranean region was used as the reference area for applying regional climate scenarios and adapting them for local assessment in Sarajevo.

The Mediterranean is also recognized as one of the regions most sensitive to climate change, with a pronounced warming trend and an increased frequency of extreme climate events, making projections for this region relevant for assessing future temperatures in Sarajevo.

**Table 1.** Air temperature increase under SSP1-2.6, SSP2-4.5, and SSP5-8.5 climate scenarios for the Mediterranean region

Mean temperature (T) Change °C	Near Term (2021-2040)	Medium Term (2041-2060)	Long Term (2081-2100)
Scenario SSP1-2.6	0.9	1.1	1.3
Scenario SSP2-4.5	0.8	1.4	2.2
Scenario SSP5-8.5	1.0	2.1	4.6

Source: IPCC WGI Interactive Atlas, 2025.

The methodological projections of air temperature increase up to the year 2100 under the specified scenarios were based on measured air temperature values from the most recent 30-year climatic period. In accordance with these indicators, a quadratic function was developed to model the temporal evolution of air temperature increase:

$$T(t) = at^2 + bt + c$$

- $(t)$  – the number of years elapsed since the reference year from which the air temperature increase is calculated;
- $(a, b, c)$  – coefficients representing the trend of the indicator increase over time.

The coefficients were determined using the least squares method, with the model fitted to the available data on average temperature and projections according to the scenarios SSP1-2.6, SSP2-4.5, and SSP5-8.5. The reference value was taken as the average temperature for Sarajevo for the period 1994–2024, while future values were defined based on projected temperature increases for the near-term (2021–2040), mid-term (2041–2060), and long-term period (2081–2100). This approach ensures that local data for Sarajevo are consistently aligned with regional scenarios.

A quadratic model was selected due to its simplicity and its ability to approximate the acceleration or deceleration of warming over the period up to 2100. The model used for projecting climate scenarios was tested using measured air temperature data for the past 100 years (1924–2024). The reference value was based on data from the first 30 years (average air temperature), after which the model was tested by projecting temperatures up to 2024. The actual average temperature for the entire observed period is 10.0°C, while the average projected air temperature is 9.9°C.

For the last 30 years (1994–2024), the average measured air temperature is 10.8°C, whereas the average projected air temperature is 11.1°C. These results (a small difference between the average actual and projected air temperatures) indicate that the model for projecting air temperature up to 2100 is fairly reliable and can be used to develop climate scenarios.

This phase of the study involved statistical processing of the collected digital meteorological data (air temperature), their modeling up to the defined period (2024–2100), as well as numerical and graphical analysis and systematic organization of the research results.

## Results

### Air temperature fluctuations in Sarajevo (1888–2024)

In the Sarajevo area, the mean annual air temperature over the entire instrumental period (1888–2024) is 9.8 °C. However, pronounced interannual variability is evident, with temperatures ranging from 7.71 °C in 1893 to 12.8 °C in 2024. Over the analyzed instrumental period of 137 years, a total of 74 years recorded mean annual temperatures above the long-term average (9.8 °C), while during 63 years the mean annual temperature was below this average value. The last 18 years have consistently exhibited mean annual temperatures higher than the long-term average. The overall trend in temperature change is best represented by a linear trend, which serves as a dynamic mean of the entire temperature series. Based on the linear trend, it was determined that the mean annual air temperature in the Sarajevo area increased by 1.7 °C over the full 137-year instrumental period.

Based on the analysis of general thermal characteristics, four predominant long-term periods can be distinguished, during which either an increasing or decreasing trend in average air temperature values prevailed, as best illustrated by the polynomial trend line.

The first characteristic period was recorded from 1888 to 1925, with reduced temperatures averaging 9.20 °C, approximately 0.60 °C below the established normal value. A prevailing increase in mean annual temperatures characterizes the second period (1926–1961), although several mostly single-year interruptions with lower temperature averages were observed. The period mean during this interval was 9.82 °C, 0.02 °C above the normal average temperature.

The next period (1962–1986) was marked by a renewed predominance of decreasing temperatures, with a period mean of 9.45 °C, i.e., 0.35 °C below the normal temperature, indicating a less pronounced cooling compared to the first period. The final fourth period, spanning 1987–2024, exhibits the most pronounced temperature increase, as indicated by a period mean of 10.62 °C, 0.82 °C above the long-term average air temperature.

To further illustrate air temperature fluctuations in Sarajevo, overlapping five-year and ten-year moving averages were analyzed. Compared to the actual mean annual temperatures, these moving averages significantly smooth out pronounced oscillations, making it easier to identify time intervals with distinct temperature trends.

The first such interval was recorded at the beginning of the instrumental period (1888–1895), with

markedly low temperatures (8.95 °C, 0.95 °C below the instrumental mean), a characteristic also observed across the European continent at the beginning of the 20th century.

From 1896 to 1905, temperatures increased slightly, with a period mean of 9.35 °C, still 0.45 °C below the long-term average. The period 1906–1913 was characterized by cooling, with the average overlapping mean temperature at 8.93 °C, 0.87 °C below the mean. A new phase of mild warming occurred from 1914 to 1924, with a period mean of 9.40 °C, followed by a six-year period (1924–1930) of more pronounced warming, reaching 9.91 °C, 0.11 °C above the instrumental mean.

During 1931–1943, interannual temperature variations were very pronounced, with one- to two-year intervals of alternating increases and decreases relative to the normal value. The period mean was 9.47 °C, 0.33 °C below the instrumental mean.

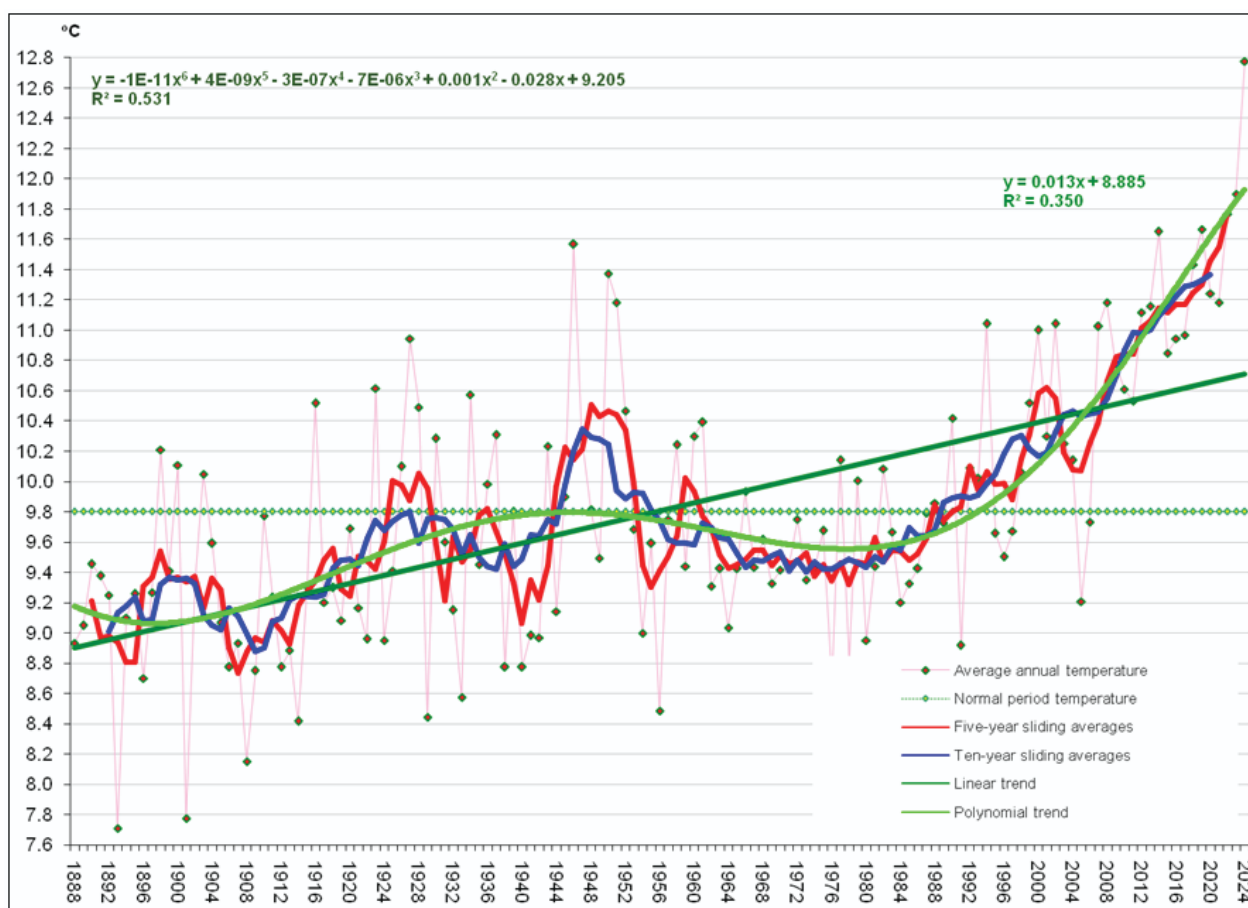
A subsequent warming phase occurred from 1944 to 1953, with a mean temperature of 10.27 °C, representing the second warmest interval in the entire

instrumental record, 0.47 °C above the mean. This is confirmed by the exceptionally high mean annual temperature of 11.57 °C recorded in 1946, comparable to modern values.

Following this warming, an eight-year period (1953–1961) of slight temperature decline occurred, with an average of 9.63 °C. A further cooling trend defined the period 1962–1974, with an average temperature of 9.50 °C, although three single-year intervals exceeded the period mean. Similar thermal characteristics were observed during 1975–1986, although interannual variability was more pronounced, with the period mean at 9.47 °C.

The period 1987–2002 exhibited a marked warming trend, as all mean annual temperatures, except for two years, were above the instrumental mean. The average temperature was approximately 10.0 °C, representing one of the most pronounced 20th-century warming episodes (Drešković & Hrelja, 2025a).

From 2002 to 2024, the trend of significant warming continued, with an average temperature of approximately 10.9 °C, 1.1 °C above the long-term mean.



**Figure 2.** Air temperature fluctuations in Sarajevo for the period 1888–2024.

Source: Authors, based on data from the FHMZBiH

The trajectories of ten-year overlapping moving averages highlight long-term temperature trends. The first period (from the start of the instrumental record to 1906) shows a general warming trend, despite a shorter three-year interval of cooling. The period mean was 9.19 °C, 0.61 °C below the instrumental mean.

The period 1907–1914 was marked by a strong cooling trend, with a period mean of 9.05 °C, representing the most intense cooling within the entire instrumental record, 0.75 °C below the mean.

From 1915 to 1928, temperatures showed a renewed upward trend, with a period mean of 9.51 °C. The thermal regime from 1929 to 1936 was characterized by predominant stagnation of averaged temperatures around 9.65 °C. The subsequent shorter period (1937–1942) showed slight cooling, with a mean of 9.50 °C. This was followed by a period of intense warming from 1943 to 1951, with a mean temperature of 10.1 °C.

During the relatively long period 1952–1971, temperatures tended to decline, resulting in a mean of 9.66 °C, although several shorter intervals exhibited posi-

tive trends, notably a three-year warming at the end of this period (Drešković & Hrelja, 2025a).

From 1971 to 1986, averaged temperatures predominantly stagnated around 9.47 °C, with alternating short intervals of increases and decreases. The final period (1986–2024) is characterized by pronounced warming, with a high period mean of 10.4 °C.

Based on the graph, the continuation of the warming trend observed in the last period can also be expected, likely resulting in further increases in period mean temperatures.

### Projections of air temperatures in Sarajevo (2024–2100)

In accordance with the established methodology, projections of air temperature in Sarajevo were made for three climate scenarios: SSP1-2.6, SSP2-4.5, and SSP5-8.5, across three periods: 2021–2040 (near-term), 2041–2060 (medium-term), and 2081–2100 (long-term).

Under all the scenarios, an increase in air temperature is observed up to 2100, with the magnitude of warming varying depending on the scenario considered.

**Table 2.** Climate scenarios SSP1-2.6, SSP2-4.5, and SSP5-8.5 – projected air temperature increase for Sarajevo

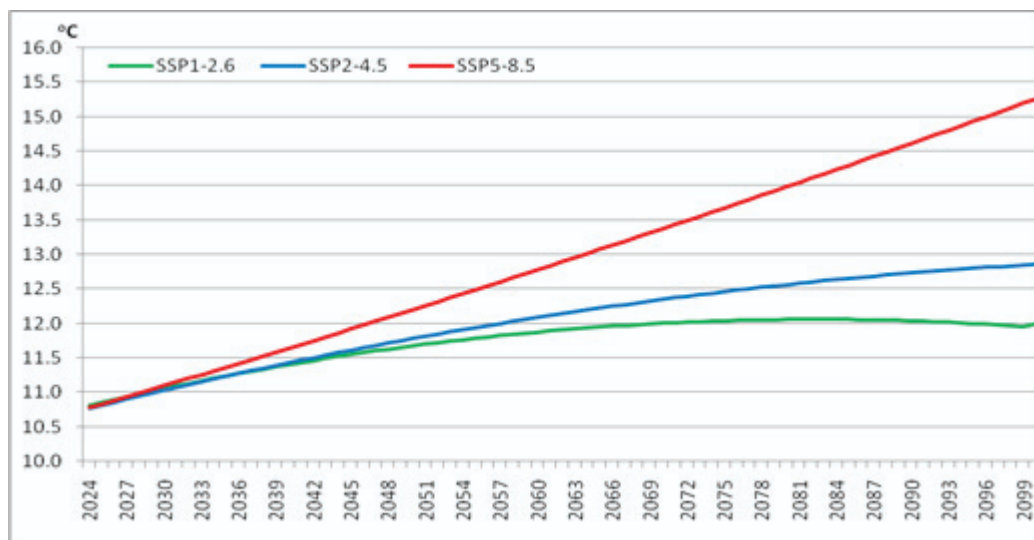
Mean temperature (T) Change °C	Near Term (2021-2040)	Medium Term (2041-2060)	Long Term (2081-2100)
Scenario SSP1-2.6	11.4	11.9	12.0
Scenario SSP2-4.5	11.4	12.1	12.9
Scenario SSP5-8.5	11.6	12.8	15.3

Source: Authors, based on FHMZBiH data and IPCC projections

According to the SSP1-2.6 climate scenario, the average air temperature in Sarajevo for the period 2024–2100 is projected to reach 11.7 °C, which represents an increase of 1.9 °C compared to the average air temperature over the previous 137 years (1888–2024).

Under this scenario, the projected average air temperatures would be 11.4 °C in 2040, 11.9 °C in 2060, and 12.0 °C in 2100.

According to the second, medium-emission scenario (SSP2-4.5), with moderate greenhouse gas emissions, the average air temperature in the period 2024–2100 is expected to reach 12.0 °C. Under this scenario, the projected average air temperatures for the near, medium, and long term would be slightly higher compared to the previously analyzed scenario. Specifically, the average air temperature would be 11.4 °C in 2040, 12.1 °C in 2060, and 12.9 °C in 2100.



**Figure 3.** Climate scenarios SSP1-2.6, SSP2-4.5, and SSP5-8.5 for the projected increase in air temperature in Sarajevo. Source: Authors, based on FHMZBiH data and IPCC projections

The most pessimistic scenario, based on assumptions of very high greenhouse gas emissions (SSP5-8.5), projects that air temperatures in Sarajevo will reach significantly higher values than those projected under the previously analyzed scenario (SSP2-4.5). In the period 2024-2100, the average air temperature in Sarajevo under the SSP5-8.5 scenario is expected to be 12.9 °C, which would represent an increase of 3.1 °C compared to the previously analyzed period (1888–2024). According to this scenario, the average air temperature in 2040 will be 11.6 °C, in 2060 it will reach 12.8 °C, and by 2100 the average temperature is projected to rise to 15.3 °C.

## Discussion

The results of this study clearly demonstrate a long-term warming trend in Sarajevo over the period 1888–2024, with a total increase of 1.7 °C in mean annual air temperature. This finding is directly supported by the results section, particularly the linear trend analysis and the persistence of above-average temperatures in the last two decades. The fact that the last 18 years all exceed the long-term mean (9.8 °C) indicates a clear shift toward a warmer climate regime rather than short-term variability.

The identified phases of warming and cooling further confirm that, although natural variability is present, the most recent period (1987–2024) is characterized by the strongest and most consistent warming. The mean temperature of 10.62 °C in this period (0.82 °C above the long-term average) highlights the acceleration of warming in recent decades. This result is consistent with previous studies for Bosnia and Herzegovina, which also report intensified warming

since the late 20th century (Trbić et al., 2022; Drešković & Hrelja, 2025a).

When compared with regional studies, the warming trend observed in Sarajevo is in line with broader patterns across the Western Balkans and Southeast Europe. Previous research indicates temperature increases of approximately 1.0–1.2 °C in the region, while projections suggest continued warming throughout the 21st century (Popov et al., 2018; Vuković & Vujadinović, 2018). In this context, the warming of 1.7 °C recorded in Sarajevo appears slightly higher, which may be partly explained by local factors such as basin topography and urbanization effects. Similar behaviour has been observed in cities with comparable geographic settings, where limited air circulation and urban heat island effects contribute to higher temperature increases.

The projected temperature changes based on SSP scenarios indicate a continuation of the warming trend under all future pathways. However, these projections should be interpreted with caution. Climate scenarios are not predictions but plausible representations of future conditions based on different assumptions about greenhouse gas emissions and socio-economic development. Uncertainty arises from differences between climate models, emission pathways, and regional climate responses. Therefore, the projected values (e.g., up to 15.3 °C under SSP5-8.5) should be understood as potential outcomes within a range of possibilities rather than precise forecasts.

Despite these uncertainties, the differences between scenarios clearly illustrate the importance of emission pathways. The relatively moderate increase under SSP1-2.6 compared to the substantial warming

under SSP5-8.5 highlights the strong influence of mitigation policies on future temperature conditions.

Certain limitations of this study should also be acknowledged. First, the analysis is based on data from a single meteorological station (Bjelave), which, although homogeneous and long-term, may not fully capture spatial variability within the Sarajevo area. Second, the projections are derived using a simplified quadratic model, which may not fully represent the complexity of climate system dynamics. Third, the study focuses exclusively on air temperature and does not include other important climatic variables such as precipitation or extreme weather indices. Additionally, the influence of urbanization on temperature trends is not quantitatively assessed, although it is likely to play a role in the observed warming.

Overall, the results provide clear evidence of significant warming in Sarajevo and confirm that local temperature trends follow broader regional patterns. At the same time, the study contributes to a better understanding of long-term temperature dynamics in a geographically specific urban basin, highlighting the importance of both regional climate processes and local environmental factors.

## Conclusion

Based on the results, the following general conclusions can be drawn:

- Global temperatures are continuously rising. Meteorological measurements indicate that the global temperature has increased by 1.1 °C compared to the pre-industrial period. The global mean temperature between 2013 and 2023 was 1.19–1.22 °C higher than the pre-industrial level, making it the warmest decade in recorded history.

- Temperatures in Europe are increasing faster than the global average. Over the same period, temperatures across the European continent rose by 2.1 °C.

- The basic characteristic of the thermal-precipitation regime in Bosnia and Herzegovina is warming or humid stagnation. In Sarajevo, where the longest meteorological measurements and observations have been conducted, linear trends for air temperature and precipitation show positive increases of 1.7 °C and 14 mm, respectively.

- Despite certain fluctuations (periods of rising and falling temperatures in Sarajevo), recent decades show a continuous increase in air temperature. This trend is projected to continue in the future. By 2100, all analyzed scenarios indicate a further rise in temperature. The projected average temperatures for the period 2024–2100 are: 11.7 °C according to SSP1-2.6, 12.0 °C according to SSP2-4.5, and 12.9 °C according to SSP5-8.5.

- Highlighted weather conditions contribute to the occurrence of climate-induced natural hazards such as droughts, floods, landslides, forest fires, and similar events, which have severe consequences for humans, natural systems, and material assets. The risks associated with these processes can be mitigated through the development of climate risk models, which can then inform responsible spatial planning, the establishment and enforcement of relevant legal frameworks, and the creation of protection and adaptation plans.

Based on these findings, there is a clear need for significantly increased efforts in the measurement and monitoring of climatic elements, as well as in modeling and forecasting climate-induced natural hazards across the entire territory of Bosnia and Herzegovina. Such monitoring and modeling are essential for guiding adaptation and mitigation strategies aimed at reducing the impacts of climate change on natural and social resources.

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