

Spatial Analysis of Air Temperature in Serbia Using GIS-Based Interpolation Methods

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Abstract—Air temperature represents one of the most important climatic parameters influencing environmental processes and human activities. This study presents a spatial analysis of air temperature distribution across the territory of the Republic of Serbia using Geographic Information Systems (GIS). The analysis is based on data from 47 meteorological stations and primarily covers the period 2022–2024, with December 2021 data included for the calculation of the winter 2021/2022 season. Mean annual, mean summer, and mean winter air temperatures were derived from official meteorological yearbooks and integrated into a geo-spatial database. Spatial interpolation was performed using the Inverse Distance Weighting (IDW) and Ordinary Kriging methods. Resulting raster datasets were clipped to the national boundary to ensure spatial consistency and comparability. The interpolated maps illustrate clear spatial patterns of temperature distribution, with noticeable seasonal differences and pronounced variations related to topographic characteristics. A visual comparison of the applied interpolation methods indicates that Kriging produces smoother temperature surfaces, while IDW emphasizes local variability around measurement stations. The results confirm the applicability of GIS-based interpolation techniques for climate-related spatial analyses and provide a reliable basis for further environmental and climatological studies in Serbia.

Keywords— GIS, air temperature, spatial interpolation, IDW, Kriging, environmental monitoring

I. INTRODUCTION

Air temperature is a fundamental climatic parameter in environmental, geographical, and spatial analyses. Its spatial variability affects ecological processes, water resource management, agriculture, urban development, and regional planning, making temperature distribution analysis essential for climate assessment and environmental monitoring. Climate change is referred to as large variations in climate averages which exist for decades or even longer periods [1].

Meteorological observations are typically collected at discrete measurement stations. However, climate-related analyses require continuous spatial representation of temperature across entire territories. Since air temperature data (as well as other climate elements) exist most often for a limited number of stations, it is necessary to make some sort of interpolation in order to obtain a full spatial coverage [2].

Interpolation is one of the main themes in temperature analyses [3].

Geographic Information Systems (GIS) provide an efficient framework for integrating, managing, and analyzing meteorological data. GIS tools give very exact and detailed images of analysed data more effectively than traditional, usually manual techniques [4]. GIS enables the efficient processing of geospatial datasets, such as temperature measurements from diverse locations, which can then be rigorously analysed and visualised [5].

The Inverse Distance Weighting (IDW) method assumes that nearby observations have greater influence on estimated values than distant ones, emphasizing local variability. In contrast, Ordinary Kriging incorporates spatial autocorrelation through semivariogram modeling and produces statistically optimized and generally smoother surfaces. Depending on the spatial attributes of the data, interpolation accuracies vary widely among different spatial interpolation methods [6]. The interpolation models are based on the autocorrelation of near surface air temperature [7].

The main objective of this study is to analyze the spatial distribution of air temperature across the territory of the Republic of Serbia using GIS techniques. Temperature changes can be analyzed seasonally in winter (December–January–February), spring (March–April–May), summer (June–July–August), and autumn (September–October–November) [8]. In this study, particular attention is given to the extreme seasonal conditions; therefore, mean annual, mean summer, and mean winter air temperatures were interpolated using IDW and Ordinary Kriging methods in order to examine spatial patterns and assess differences between the applied interpolation approaches.

The paper is structured as follows. Section II describes the study area. Section III presents the data sources. Section IV explains the applied methodology. Section V presents the results, while Section VI provides a comparison of the interpolation methods. Section VII analyzes the influence of elevation on temperature distribution. Section VIII discusses the findings, and Section IX concludes the paper.

II. STUDY AREA

The study area covers the entire territory of the Republic of Serbia, located in Southeast Europe. The country is characterized by diverse geographical and topographic conditions, ranging from lowland areas in the north to mountainous regions in the central and southern parts. Such terrain heterogeneity significantly influences the spatial distribution of air temperature [2].

Serbia exhibits a moderate continental climate, with pronounced seasonal variations. Summers are generally warm, while winters are cold, particularly in higher-altitude areas. Temperature conditions are affected by latitude, elevation, relief configuration, and atmospheric circulation patterns.

The spatial scope of the analysis includes the national territory defined by the administrative boundary of Serbia. All interpolated temperature rasters were clipped to this boundary to ensure uniform spatial coverage and enable consistent comparison of results obtained for different years, seasons, and interpolation methods.

III. DATA

Meteorological data used in this study were obtained from official publications of the Republic Hydrometeorological Service of Serbia (RHMZ), specifically from the Meteorological Yearbooks – Climatological Data. The dataset includes records for December 2021 and complete annual data for the years 2022, 2023, and 2024.

A total of 47 meteorological stations were selected for the analysis, as these stations provide a continuous and uninterrupted temperature time series for the observed period. Although the national monitoring network includes a larger number of stations, some of them were excluded due to data gaps or irregular operation. Figure 1 shows the spatial distribution of the selected meteorological stations within the territory of the Republic of Serbia.

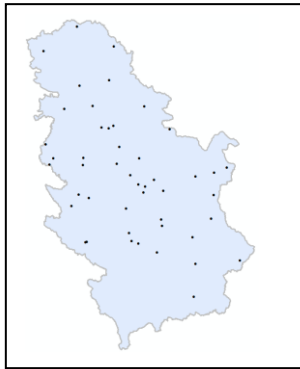


Fig. 1. Spatial distribution of the selected meteorological stations

The temporal scope of the study covers a three-year period. For each station, the following climatic parameters were derived: mean annual air temperature, mean summer air temperature calculated as the average of June, July, and August, and mean winter air temperature defined as the average of December of the previous year and January and February of the current year. All temperature values were directly extracted from the official RHMZ yearbooks available through the RHMZ website. The administrative boundary of the Republic of Serbia was obtained from the Republic Geodetic Authority (RGZ).

IV. METHODOLOGY

Meteorological station data were prepared and processed within a GIS environment. A point shapefile of meteorological stations was created based on data obtained from the RHMZ meteorological yearbooks, using official station coordinates. Each station was georeferenced. An attribute table was formed to store temperature time series for the years 2022, 2023, and 2024, along with December 2021. For every station, mean annual, mean summer, and mean winter air temperatures were calculated and entered as separate attributes, providing the input dataset for spatial analysis, as shown in Table 1.

TABLE 1 ATTRIBUTE TABLE OF THE STATION SHAPEFILE

Column name	Description
ID	Station ID
STAT_NAME	Station name
Elevation	Elevation (m)
T AVG 2022	Mean annual temperature (2022)
T S 2022	Mean summer temperature (2022)
T W 2022	Mean winter temperature (2022)
T AVG 2023	Mean annual temperature (2023)
T S 2023	Mean summer temperature (2023)
T W 2023	Mean winter temperature (2023)
T AVG 2024	Mean annual temperature (2024)
T S 2024	Mean summer temperature (2024)
T W 2024	Mean winter temperature (2024)

To convert discrete temperature measurements into continuous spatial surfaces, two spatial interpolation methods were applied: Inverse Distance Weighting (IDW) and Ordinary Kriging. Many researches have made contributions to assess the performance of various predicting NSAT models in different regions [7].

The IDW approach posits that the rate of correlation and similarity between neighbors is proportional to their proximity [9]. Due to its simplicity and ability to reflect local variability, it is commonly used in temperature distribution studies.

Ordinary Kriging is a geostatistical interpolation technique that considers both distance and spatial autocorrelation among measured values through semivariogram modeling. This approach often results in smoother interpolation surfaces and is widely applied in regional climate analyses. In terms of accuracy and precision, the use of kriging techniques in mining studies and reserve estimates has resulted in positive outcomes [10].

Both interpolation methods were employed in this study to allow comparison of their spatial performance.

Interpolation was carried out for the entire territory of the Republic of Serbia for all three analyzed years and for each temperature parameter, including mean annual, mean summer, and mean winter air temperature. In total, nine raster datasets were generated using the IDW method and nine raster datasets using the Ordinary Kriging method. All raster outputs were subsequently clipped to the national administrative boundary to ensure a uniform spatial extent.

V. RESULTS

The results of the spatial interpolation are presented through thematic maps illustrating the distribution of air temperature across the territory of the Republic of Serbia. The generated raster datasets provide insight into both annual and seasonal temperature patterns.

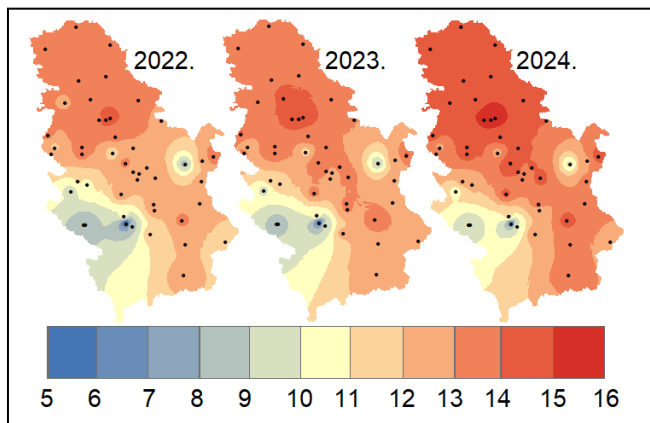


Fig. 2. Mean annual air temperature (°C, IDW)

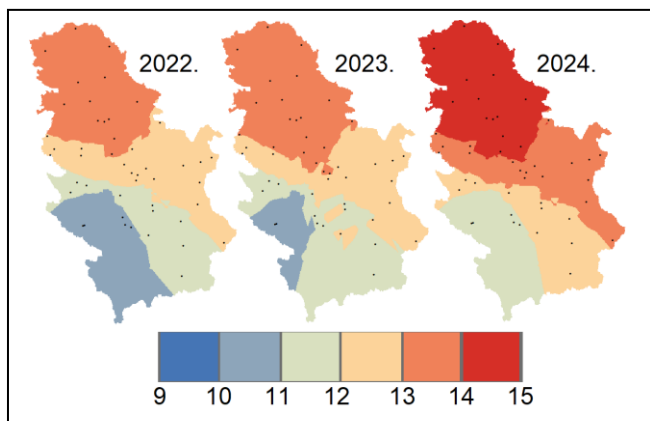


Fig. 3. Mean annual air temperature (°C, Kriging)

The raster maps presented in Figures 2–7 illustrate the spatial distribution for all three years: 2022, 2023, and 2024. The spatial distribution of mean annual air temperature obtained using the IDW method is shown in Figure 2, while Figure 3 presents the corresponding surface generated using the Ordinary Kriging method. The maps indicate clear spatial gradients, with higher mean annual temperatures generally observed in lowland areas and lower values in mountainous regions, reflecting the influence of relief and elevation.

The differences observed between the interpolation results are related to the conceptual characteristics of the applied methods. The IDW interpolation produced a wider temperature range, emphasizing local extremes and, in some areas, generating values slightly beyond the minimum and maximum recorded at meteorological stations. This behavior is a consequence of the distance-based weighting approach, which does not account for spatial autocorrelation or physical constraints of climatic variables.

In contrast, Ordinary Kriging resulted in a narrower range of interpolated temperatures. This does not indicate a loss of measured data, but rather reflects the smoothing effect of geostatistical interpolation. By modeling spatial autocorrelation, Kriging reduces the influence of isolated extreme values and estimates the most probable temperature distribution in space. As air temperature is a continuous variable that typically changes gradually over geographic space, the smoother surfaces produced by Kriging are considered more physically realistic for regional-scale climate analysis.

Both interpolation results indicate a clear temporal trend in air temperature distribution. The spatial patterns show an increase in mean air temperature from 2022 to 2023, as well as from 2023 to 2024. The difference between 2022 and 2023 is generally smaller, suggesting a gradual warming process over the analyzed period. In particular, the comparison between 2023 and 2024 reveals an almost countrywide temperature increase of approximately 1%, consistently observed across both interpolation methods.

Figures 4 and 5 display the spatial distribution of mean summer air temperature derived using IDW and Kriging interpolation, respectively. Summer temperatures exhibit pronounced regional variability, with the highest values occurring in northern and central parts of the country, while cooler conditions are evident in higher-altitude areas.

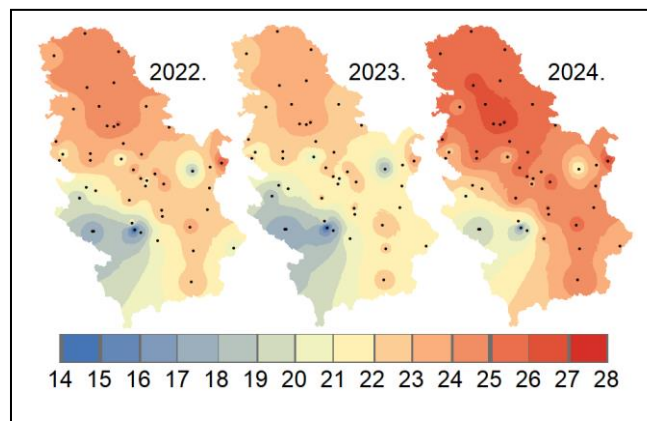


Fig. 4. Mean summer air temperature (°C, IDW)

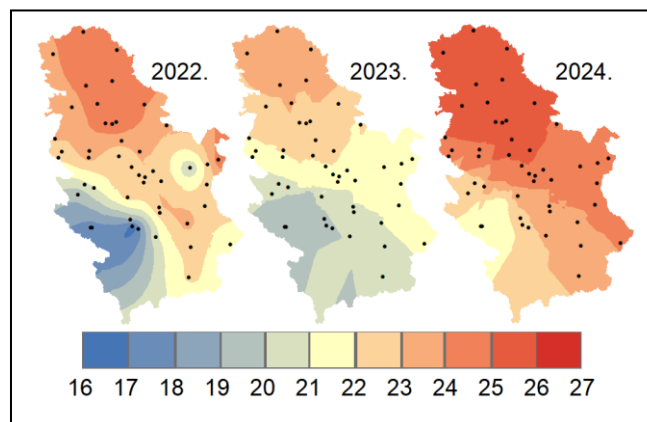


Fig. 5. Mean summer air temperature (°C, Kriging)

The spatial patterns of mean winter air temperature are presented in Figures 6 and 7. Both interpolation methods show the coldest zones concentrated in mountainous regions and southern parts of Serbia. Differences between the IDW and Kriging outputs are mainly reflected in surface smoothness, while overall spatial trends remain consistent across both methods.

Based on the analysis of all generated maps, an overall warming tendency is evident in mean annual and mean winter air temperatures, which show a consistent increase from 2022 to 2024 across most of the study area. In contrast, mean summer air temperatures exhibit greater interannual variability, with lower values observed in 2023 compared to 2022, followed by a pronounced increase in 2024. These patterns are consistently reflected in both IDW and Ordinary

Kriging interpolation results, confirming a gradual rise in annual and winter temperatures, while summer temperatures display a temporary decrease before reaching higher values in the final analyzed year.

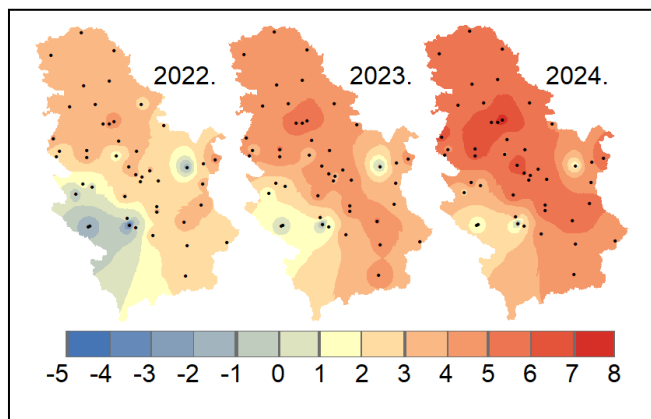


Fig. 6. Mean winter air temperature (°C, IDW)

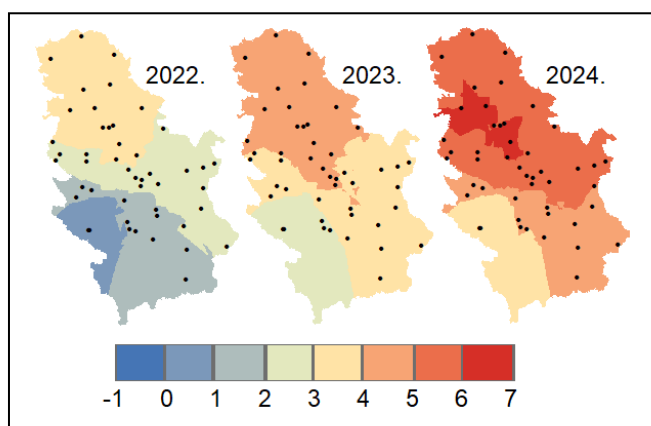


Fig. 7. Mean winter air temperature (°C, Kriging)

VI. COMPARISON OF INTERPOLATION METHODS

The comparison of interpolation results indicates that both IDW and Ordinary Kriging are suitable for spatial representation of air temperature data, although they differ in their conceptual approach and resulting surface characteristics. The IDW method relies solely on distance-based weighting, which causes interpolated values to be strongly influenced by nearby measurement stations. As a result, IDW surfaces tend to emphasize local variability and may display abrupt changes in areas with uneven station density.

Ordinary Kriging, in contrast, incorporates spatial autocorrelation between observed values through semivariogram modeling. This enables the method to account for regional temperature trends and reduces the influence of isolated extreme values. Consequently, Kriging generally produces smoother and more continuous temperature surfaces, which are often more consistent with the physical behavior of atmospheric variables. For climatic parameters such as air temperature, which typically exhibit gradual spatial variation, Kriging is commonly considered more appropriate, while IDW remains useful for rapid visualization and comparison.

VII. INFLUENCE OF ELEVATION ON TEMPERATURE DISTRIBUTION

Elevation plays a significant role in shaping the spatial distribution of air temperature across Serbia. In general, air temperature decreases with increasing altitude due to changes in atmospheric pressure and energy balance. As a result, lower temperature values are predominantly observed in mountainous regions, while higher temperatures occur in lowland and valley areas.

This relationship is clearly reflected in the interpolated temperature maps, where cooler zones correspond to higher elevations in central and southern Serbia. The combined effect of altitude, terrain orientation, and relief complexity contributes to pronounced spatial temperature gradients, particularly in regions with strong topographic variability.

VIII. DISCUSSION

The spatial analysis of mean annual and seasonal air temperatures across Serbia reveals clear patterns influenced by topography and geographic setting. Higher temperature values are generally observed in lowland areas, while lower temperatures characterize mountainous regions, reflecting the influence of elevation on air temperature distribution. Seasonal differences are pronounced, with summer temperatures exhibiting the highest spatial variability, whereas winter temperatures show a stronger dependence on relief and altitude.

The interpolated temperature surfaces indicate a short-term warming tendency primarily expressed through mean annual and mean winter temperatures, which increase progressively from 2022 to 2024. In contrast, mean summer temperatures display greater interannual variability, with lower values in 2023 compared to 2022, followed by a notable increase in 2024. The comparison between 2023 and 2024 suggests an almost countrywide temperature rise. Although the analyzed period is too short to assess long-term climate change, the results demonstrate the effectiveness of GIS-based interpolation methods in identifying short-term temperature dynamics. Differences between IDW and Ordinary Kriging are mainly reflected in surface characteristics, with IDW emphasizing local extremes and Kriging producing smoother and more physically realistic temperature fields, while both methods capture similar large-scale spatial patterns.

The choice between IDW and Ordinary Kriging depends on the purpose of analysis, data availability, and spatial characteristics of the study area. IDW may be appropriate for preliminary assessments, for datasets with relatively dense and evenly distributed measurement stations, or in applications where the emphasis is on preserving local variability around observation points. Its simplicity and lower computational requirements make it suitable for rapid spatial estimations and operational analyses. In contrast, Ordinary Kriging is generally more appropriate in heterogeneous terrains, such as regions with pronounced elevation differences, where spatial autocorrelation plays a significant role. Due to its statistical foundation and incorporation of variogram modeling, Kriging provides smoother and often more physically consistent surfaces, making it preferable for detailed climatic assessments and studies requiring higher methodological rigor. Therefore, in regions such as Serbia, characterized by diverse topographic conditions, Kriging may offer advantages for comprehensive spatial climate analysis,

while IDW remains a useful and robust alternative for simpler or exploratory applications.

IX. CONCLUSION

This study demonstrates the effectiveness of GIS-based spatial interpolation methods for analyzing air temperature distribution in Serbia. Using data from 47 meteorological stations, mean annual, summer, and winter temperature patterns were successfully represented through continuous raster surfaces.

The results highlight clear spatial and seasonal gradients, strongly influenced by elevation and regional geography. A short-term warming trend is observed over the three-year period, with temperatures increasing gradually from 2022 to 2024. The comparison of interpolation methods shows that Kriging provides smoother and more physically realistic temperature surfaces, while IDW emphasizes local variations and extreme values.

Overall, the integration of meteorological data within a GIS environment provides a valuable framework for environmental monitoring and planning. Future studies could extend this approach using longer time series, additional climatic variables, and auxiliary data such as elevation to improve interpolation accuracy and support environmental decision-making.

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