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# CLIMATE REGIONALIZATION OF SERBIA ACCORDING TO KÖPPEN CLIMATE CLASSIFICATION

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**Abstract:** The paper presents a concise overview of the theoretical framework on which climate classifications are based. Beside short review of climate classifications, namely climatic regionalization for Serbia (or wider area including Serbia), main deficiency of these research was ascertained (which primarily relate to the period on the basis of which climate regionalization was carried out). The criteria of the Köppen climate classification are presented, on the basis of which the climate regionalization of Serbia has been carried out. The methodology of making maps of air temperatures and precipitation amounts has been described, on the basis of which a map of the climate regions of Serbia has been created. Spatial distribution of the types and subtypes of the climates in Serbia has been briefly described. It has been pointed to the constraints of the climate regionalization that arise from the theoretical bases of the climate classifications, but also from nature of the collected data and the applied methodology.

**Key words**: Köppen climate classification, climate regionalization, air temperature, precipitation, Serbia

## Introduction

One of the most definitive climatic definitions is that it is "the variability of weather conditions over some space in a certain time period, represented by statistical indicators of meteorological elements" (Dunlop, 2001). This "variability of weather conditions over some space in a certain time period" is actually a manifestation of interactions within the climate system, as well as the connection of the climate system with variations of the solar activity and the long-periodic changes in the parameters of the Earth's orbit. If one takes into account the complexity of each component of the climate system, as well as the complexity of the relationship within and between the components of the climate system at different time-space scales, one can conclude that there are practically infinitely many manifestations of these interactions on Earth. Given that in practice it is not necessary (and it is not possible) to work with such a large number of climates, it is necessary to carry out their classification. Concerning climate classifications, Barry & Chorley (2003) state that "the purpose of any classification system is to achieve an efficient information organization that would be presented in a simplified and generalized form. Climate statistics should be organized in a way that would describe and highlight the main types of climate, and it is obvious that each individual climate classification can serve only one or a few purposes". Precisely the purpose for which the climate classification is performed (for example, investigation of the spatial distribution of different types of vegetation; the examination of the genesis of different types of soil; bioclimatic research; the examination of climate conditions for the needs of certain industries) defines the selection of variables to be used in a climate classification. Khlebnikova (2009) states that the scientific and practical value of climate classifications is reflected in the understanding of physical mechanisms affecting the climate, as well as in the assessment of the climate potentials of a certain part of the Earth from the aspect of their use. Although the boundary between these types of values and knowledge is not always sharp, certain types of climate classifications are somewhat more oriented either toward cognitive/scientific (generic and numerical climate classifications) or practical/usable values (empirical climate classifications).

Köppen climate classification is used in this paper for which Kotteki, Grieser, Beck, Rudolf, & Rubel (2006) are convinced that, although developed in the first half of the twentieth century, it has not lost on actuality up to date, and with the development of climate data sets of high (spatial) resolution and use in climate models it will also be applicable in the future.

It is important to note that climate classifications represent in themselves abstract systems which, by application in space, affirm their value (Milovanović, 2010). According to this author, the application of climate classifications to a certain space, that is, the separation of spatial units based on climate specificities defined through the climate classification represents climate regionalization.

Climate regionalization for the territory of Serbia (or a wider area that includes Serbia) was done by a greater number of authors. The first was made by Jovan Cvijić (1922), followed by Milutinović (1974); Savić (1979); Obuljen (1979); Rakićević (1980); Kolić (1988); Ducić and Radovanović (2005). However, all the above mentioned works are based on older observation periods (1931–1960 and 1961–1990), with the latter being updated with the data for the period 1961–2010 in Milovanović, Radovanović, Stanojević, Pecelj and Nikolić (2017a), while Stojsavljević (2015) singled out a number of temperature and precipitation regions in Serbia by applying the (geo) statistical procedures on climate data observed in the period 1971–2010. It is important here to point out the existence of the Atlas of the Climate of the SFR of Yugoslavia and the accompanying annexes made by Ranković, Radičević and Sokolović-Ilić (1981) and Sokolović-Ilić and Radičević (1984) based on observations from 1931 to 1960. Although the climate regionalization of the SFR of Yugoslavia (and Serbia within it) was not done in this unique and valuable whole, all the elements that could serve it were prepared (among others, maps with mean monthly and mean annual values of air temperatures and precipitation amounts were made).

From the above mentioned, a small number of papers can be noticed examining the observation period up to 2010 and also the absence of a map of the climate regions according to the Köppen classification for this period. Therefore, removing this shortcoming has been set as one of the main goals of this paper.

## Used data and methods

According to Ducić & Andjelković (2004), the climate as the highest hierarchical level in the Köppen classification is determined according to the value and duration of certain mean temperatures; the type is determined by the precipitation regime, while the subtype is determined by the time of temperature and precipitation extremes. The same authors state that Köppen climate classification can be well understood only if one learns about the method of determining a climate formula — a short symbolic description of the climate in which the climate features are replaced by a series of letters (Table 1).

Considering that there is no dry season in Serbia in the classical sense of this word, the second letter in the climate formula, that is, the type of climate would be f for the whole Serbia. However, according to Milovanović et al. (2017a) there are some differences in the pluviometric regime of precipitation in Serbia. In Metohija and in the far southwest of the country, a maritime pluviometric regime is dominant, which is characterized by slightly higher precipitation in the cooler part of the year and maximum precipitation in one of the winter months. The transient type of pluviometric regime is present in Kosovo, Negotinska Krajina and Ključ, where the values of the maximum in November/December and May/June are very close or practically equal, while the Danube variant of the continental pluviometric regime is represented in the rest of the country (expressive May/June precipitation maximum, with a secondary maximum in November/December). For the purposes of this paper, additional markings have been introduced for the continental pluviometric regime (higher precipitation in May/June than in November/December — mark q) and for the maritime pluviometric regime (higher precipitation in November/December than in May/June — mark r).

Table 1. Köppen climate classification (according to Ducić & Anđelković, 2004)

| Climate | Name | Features[1] |
|---|---|---|
| A | Tropical humid climate | Lowest Tm> 18 ºC |
| B | Dry climate | Dry boundary (boundary toward forests) is: for the precipitation period in winter: Rg <2Tg for fuzzy precipitation: Rg <2Tg + 14 for the precipitation period in summer: Rg <2Tg + 28 |
| C | Moderately warm climate | The lowest Tm is between 18 ºC and -3 ºC |
| D | Moderately cold climate | Highest Tm> 10 ºC, and the lowest Tm <-3 ºC |
| E | Cold climate | Highest Tm <10 ºC |
| **Type** | **Name** | **Features** |
| S | Steppe climate | The boundary between the steppes and the deserts is: for the precipitation period in winter: R = Tg for fuzzy precipitation period: R = Tg + 7 for the precipitation period in the summer: R = Tg + 14 |
| W | Desert climate | |
| f | Humid climate | No dry season |
| m | Monsoon climate | The rainy period compensates for the scarcity in the dry season |
| s | Dry summer | summer is the driest season |
| w | Dry winter | winter is the driest season |
| T | Tundra climate | The highest Tm is between 0 ºC and 10 ºC |
| F | Climate of the eternal frost | Highest Tm below 0 ºC |
| **Subtype** | **Name** | **Features** |
| h | Hot climate | Tg> 18 ºC |
| k | Cold climate | Tg< 18 ºC, and the highest Tm> 18 ºC |
| a | Hot summer | Highest Tm> 22 ºC |
| b | Warm summer | Highest Tm< 22 ºC, and least 4Tm> 10 ºC |
| c | Cool summer | Less than 4 Tm> 10 ºC, and the lowest Tm> −38 ºC |
| d | Very cold winter | Lowest Tm< −38 ºC |

[1]Tm — mean monthly temperature; Tg — mean annual temperature; R — amount of rainfall

Data on mean monthly and average annual air temperatures and average monthly and average annual precipitation in the period 1961–2010 were used in the paper from 64 climatological stations and 421 precipitation stations. Except for the territory of Kosovo and Metohija, for which we had data series from only 7 stations (which was especially necessary to fill in after 1999), the rest of Serbia on the terrain up to 500 m above sea level is well and evenly "covered" with meteorological stations, while with the rise of altitude their number decreases (Milovanović, Schuster, Radovanović, Ristić Vakanjac, & Schneider 2017b).

For the development of regression models based on which interpolation of air temperatures and precipitation was done, the latitude, longitude and altitude of the climatological, i.e. precipitation stations are used as predictor variables, whereas the mean value and standard deviation of the slopes and terrain exposures are calculated from circular zones of 10 km diameter formed around the stations on the basis of the SRTM (Shuttle Radar Topography Mission) of the Digital Elevation Model (DEM) in a resolution of 30x30m.

Due to later phases of work, the two auxiliary rasters were formed for longitude and latitude. The selection of the predictors is made based on the significance they have in the regression model. It turned out that in the case of precipitation, the largest percentage of variance has been a combination of longitude, altitude and mean terrain elevation around the station. The coefficient of determination ranges from 0.32 in December to 0.59 in May (Table 2).

Table 2. Parameters of regression model for precipitation amounts

| **Dependent precipitation variable** | **Significance of the predictor (t value/p level)** | | | **Adapted coefficient of determination ($R^2$)** |
|---|---|---|---|---|
| | Longitude | Altitude | Inclination | |
| I | −6.10 / 0.01 | 3.97 / 0.01 | 7.47 / 0.01 | 0.34 |
| II | −3.48 / 0.01 | 4.80 / 0.01 | 8.47 / 0.01 | 0.41 |
| III | −5.60/ 0.01 | 4.75 / 0.01 | 9.08 / 0.01 | 0.43 |
| IV | −2.73 / 0.01 | 5.11 / 0.01 | 9.58 / 0.01 | 0.47 |
| V | −9.34 / 0.01 | 6.92 / 0.01 | 12.01 / 0.01 | 0.59 |
| VI | −15.81 / 0.01 | 2.41 / 0.02 | 6.31 / 0.01 | 0.41 |
| VII | −20.27 / 0.01 | 2.95 / 0.01 | 8.30 / 0.01 | 0.53 |
| VIII | −21.19 / 0.01 | 3.09 / 0.01 | 7.90 / 0.01 | 0.55 |
| IX | −17.64 / 0.01 | 6.30 / 0.01 | 9.19 / 0.01 | 0.56 |
| X | −10.91 / 0.01 | 5.46 / 0.01 | 8.35 / 0.01 | 0.48 |
| XI | −7.76 / 0.01 | 7.26 / 0.01 | 8.76 / 0.01 | 0.50 |
| XII | −5.34 / 0.01 | 3.55 / 0.01 | 7.43 / 0.01 | 0.32 |
| Yearly | −12.77 / 0.01 | 5.45 / 0.01 | 10.03 / 0.01 | 0.51 |

When the air temperature is viewed as the dependent variable, the most important predictors are altitude and latitude (Table 3). The coefficient of determination in the model is much higher than in the case of precipitation and ranges from 0.75 in January to 0.93 in May.

Table 3. Regression model parameters for air temperatures

| **Dependent air temperature variable** | **Significance of the predictor (t value / p level)** | | **Adapted coefficient of determination ($R^2$)** |
|---|---|---|---|
| | Altitude | Latitude | |
| I | −13.2 / 0.01 | −4.56 / 0.01 | 0.75 |
| II | −18.6 / 0.01 | −6.4 / 0.01 | 0.86 |
| III | −22.1 / 0.01 | −6.4 / 0.01 | 0.90 |
| IV | −27.1 / 0.01 | −5.24 / 0.01 | 0.93 |
| V | −25.8 / 0.01 | −2.7 / 0.01 | 0.93 |
| VI | −23.9 / 0.02 | −3.4 / 0.01 | 0.92 |
| VII | −19.6 / 0.01 | −3.5 / 0.01 | 0.88 |
| VIII | −18.0 / 0.01 | −3.9 / 0.01 | 0.86 |
| IX | −17.7 / 0.01 | −4.0 / 0.01 | 0.85 |
| X | −15.5 / 0.01 | −3.8 / 0.01 | 0.81 |
| XI | −14.8 / 0.01 | −4.3 / 0.01 | 0.80 |
| XII | −14.0 / 0.01 | −4.4 / 0.01 | 0.77 |
| Yearly | −20.8 / 0.01 | −4.8 / 0.01 | 0.89 |

In the next step, the dataset is divided into a subset for interpolation (90% of stations) and a subset to test the accuracy of modelled air temperature and precipitation values (10% of stations). In the interpolation subset, by multiplying the coefficients from the regression model with the values of the selected predictors for each station and subtracting the values thus obtained from the observed ones, new values of air temperature and precipitation are formed, of which a separate layer is made by the application of the kriging method, which is then transferred to the raster form. By multiplying coefficients from a regression model with the corresponding rasters (DEM, auxiliary raster for longitude, auxiliary raster for latitude) and adding to the previously formed rasters of air temperatures and precipitation, raster maps were obtained. The accuracy of the applied approach is checked by comparing the values of air temperatures / precipitation from the stations from the testing subset and the values of the pixels in which the stations are located. The difference between the modelled and observed values in such a way is expressed through the mean absolute error (MAE) and the root mean square error (RMSE).

Table 4. Mean absolute error (MAE) and root mean square error (RMSE) of the modelled air temperature and precipitation values

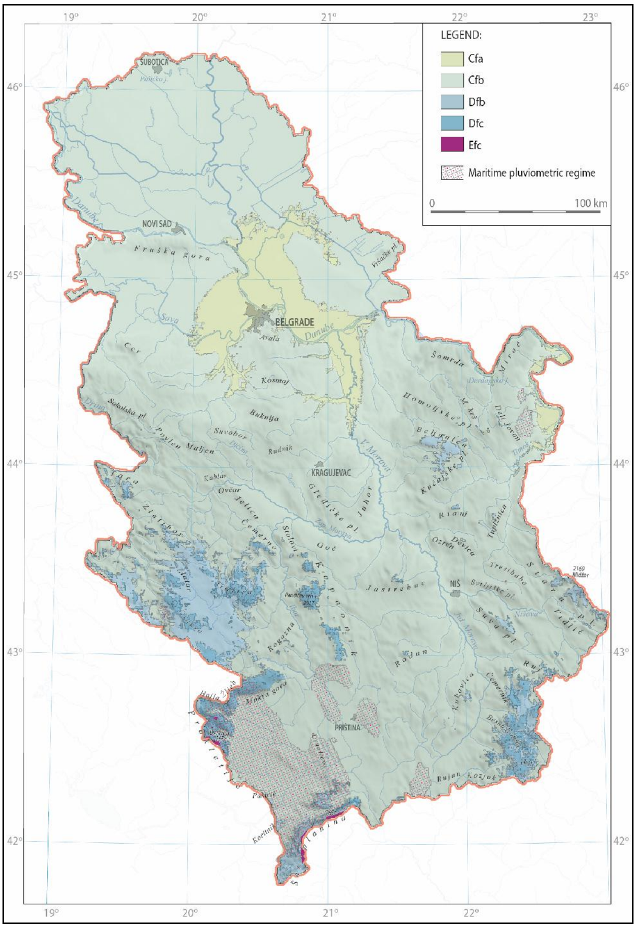
| | Air Temperature (ºC) | | Precipitation (mm) | |
|---|---|---|---|---|
| | RMSE | MAE | RMSE | MAE |
| I | 0.2 | 0.2 | 4.9 | 3.5 |
| II | 0.2 | 0.2 | 4.0 | 3.2 |
| III | 0.5 | 0.4 | 5.3 | 3.7 |
| IV | 0.5 | 0.4 | 6.2 | 4.4 |
| V | 0.6 | 0.4 | 4.3 | 3.2 |
| VI | 1.5 | 0.7 | 5.8 | 4.6 |
| VII | 0.6 | 0.4 | 5.2 | 4.1 |
| VIII | 1.1 | 0.8 | 5.4 | 3.6 |
| IX | 0.8 | 0.5 | 4.5 | 3.5 |
| X | 0.6 | 0.5 | 3.9 | 2.9 |
| XI | 0.2 | 0.1 | 5.6 | 4.1 |
| XII | 0.4 | 0.3 | 5.9 | 4.3 |
| Yearly | 1.0 | 0.7 | 68.0 | 46.6 |

At air temperatures, the smallest errors in the absolute amount are during January, November and December (0.1–0.2 ºC), and the highest during June and August (MAE from 0.7 to 0.8 ºC; RMSE from 1.1 to 1.5 ºC). At the annual level, the mean absolute error is 0.7 ºC, and the root mean square error is 1.0 ºC. When precipitation is observed, the minimum errors are during October, February and May (MAE from 2.9 to 3.2 mm; RMSE from 3.9 to 4.3 mm), and the highest during April and June (MAE from 4.4 to 4.6 mm; RMSE from 5.8 to 6.2 mm). At the annual level, the mean absolute error at precipitation is 46.6 mm, and the root mean square error is 68.0 mm.

## Results and discussion

Based on the previously described methodology, twenty-six maps of air temperatures and precipitation (twelve maps with monthly values, respectively and one map with annual values, respectively) were formed. By applying the criteria shown in the Table 1 on the map of the average January air temperatures (selected due to a limit value greater than or less than −3 ºC), then the May, June, July, August and September air temperatures (selected due to the possibility of exceeding the temperature of 10 ºC), as well as by “overlapping” of maps of the average May and June precipitations with the maps of mean November and mean December precipitations, a map of the climate regions of Serbia was obtained (Map 1).

Map 1. Climate regions of Serbia according to Köppen climate classification




Cfbq climate is most dominated, which gets into Cfbr in a small move east of Deli Jovan and Miroč, and the Efcr climate is least represented, being on terrains above 2,250 m at the Prokletije and the Šara mountains. Cfaq climate is present in the part of Veliko Pomoravlje, Šumadija, middle and southern Banat, Srem, Ključ and Negotinska Krajina (on terrains up to 120–140 meters above sea level). Dfbq climate is present on lowland terrains of Central Serbia, which gets into Dfbr in a small area west of Giljevo. Dfcq climate is present in mountainous terrains (above 1,200 meters above sea level) in south-western, southern and south-eastern Serbia, while Dfcr climate is at heights of 2,250 meters at the Prokletije and the Šara.

Presented boundaries should be accepted with a reservation for several reasons. As already mentioned, each climate classification implies a certain degree of generalization, which implicitly indicates that, depending on the scale of the climate regionalization, it is not possible to include, show and explain the influence of each of the climate factors, that is, climate modifiers. Thus, at the core of a macroclimate region, which is largely defined by its latitude, global or secondary circulation of the atmosphere, the land and sea layout, there are many climatic meso-regions influenced by, for example, characteristics of the relief, and in the climatic meso-regions there is again a huge number of climatic micro-regions, which are affected by, for example, the nature and characteristics of soil and plant cover. Bearing in mind the previously stated, as well as the fact that the values of climate elements in nature are changing gradually, any withdrawn boundary between adjacent climate regions cannot be freed from arbitrariness, as even such limited climate regions are not homogeneous in terms of their climate characteristics (Arnfield https://www.britannica.com/topic/classification-1703397).

The second group of reasons relates to the methodology of determining the values of climate elements in a given area. Since the "image" of the climate of a given space is obtained from the data from a limited number of often unevenly distributed meteorological stations, it remains insufficiently known what are the values of climate elements in a space where there are no meteorological observations. Therefore, for areas where there are no measurements, it is necessary (knowing the effects of different climate factors) to interpolate the values of climate elements. Chilès and Delfiner (1999) indicate that the central problem in such investigations is the reconstruction of a certain phenomenon based on the values obtained from a limited number of points. In the interpolation of the values of climate elements, the lack of observations from a sufficiently large number of meteorological stations can be replaced by the use of indirect data (e.g. data on the area where meteorological stations are located - their altitude, latitude, longitude, distance from the sea) and the establishment of a functional dependence of the values of climate elements on these data. However, as we have seen in the example of the model that we used in this paper, the obtained values are very dependent on the selection of the predictors to be used in the formation of the model, the accuracy of the model itself and the choice of interpolation techniques.

The third group of reasons relates to the nature, quality and availability of the data in question. It has already been mentioned that a certain number of series were necessary to fill in (which raises the question of the adequacy of the techniques for filling in the series and their homogeneity). Then, the coordinates of the meteorological stations from which the data on air temperatures and precipitation were collected are given with an accuracy of one minute, which means that in our latitudes the position of the station is determined somewhere in the field of dimensions of about 1.8 km x 1.8 km. Finally, if the quality of the model that would be used to find the values of climate elements needs to be improved with information on, for example, types of soil and vegetation, degree of construction, etc., there remains a question of technical possibilities for collecting such data.

## Conclusion

In order to determine the climate regions of Serbia according to Köppen climate classification, it was previously necessary to determine the spatial distribution of mean monthly and annual air temperatures and precipitation in the period 1961–2010. Because of that, regression models were created in which the mentioned climate elements were dependent variables, while the latitude, longitude, altitude and terrain characteristics (inclination and exposition) on which the stations were located were investigated as predictors. In this way, a total of twenty-six maps of average monthly and average annual air temperatures and precipitation were formed. Applying the criteria of the Köppen climate classification on these maps, the climate regions of Serbia were determined.

The Cfbq climate has the largest spatial distribution, which gets into the Cfbr in a small area in eastern Serbia. The Efcr (at Prokletije and Šara mountains) is the least represented. The Cfaq climate is present on terrains up to 120–140 meters above sea level in central Serbia and Vojvodina. The Dfbq climate is present on the lowland terrains of Central Serbia, which gets into the Dfbr in a small area west of Giljevo. The Dfcq climate is present in mountainous terrains (above 1 200 meters above sea level) in south-western, southern and south-eastern Serbia, while the Dfcr climate is at heights of 2,250 meters at Prokletije and Šara.

An attempt was also made in the paper to define and systematize the problems that were characteristic for climate classification, i.e. climate regionalization, and were also important during the formation of the presented climate regionalization of Serbia.

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