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Contribution to the study of climate change in Serbia using continentality, oceanity, and aridity indices

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Abstract— The aim of the study is to present some specific climatic conditions on the territory of the Republic of Serbia based on the analysis of four climate indices, which can help in understanding contemporary climate changes. Temperature and precipitation data from 31 meteorological stations for the period 1951–2010 were used. The relative homogeneity of the data series was done using the MASH v3.02 method. The indices used are: Johansson Continentality Index, Kerner Oceanity Index, De Martonne Aridity Index, and Pinna Combinative Index. Geospatial analysis of the distribution of the values of the four mentioned indices was done using the QGIS package 2.8.1. The results of the research show that the continentality effect is present in most of Serbia, while oceanity is observed locally, mainly in the western and southwestern parts of the country. The further analysis showed that there is no dry and semi–dry Mediterranean climate in Serbia. Considering that it is dry in the warmest part of the year (July–September), when the need for water is increased, which is clearly shown by the Walter climate diagram, as well as the fact that an increase in temperature and a decrease in precipitation during the vegetation period were observed in the second 30–year period (1981–2010), it can be concluded that in Serbia there is a tendency towards arid climate. The results presented in this paper can help decision makers to plan certain climate change adaptation measures.

Key-words: climate indices, continentality, oceanity, aridity, QGIS, Serbia

1. Introduction

Based on the analysis of monthly, seasonal, or annual values of temperature and precipitation, a general picture of the climate of a given area can be obtained. But, very often, it is necessary to determine some specifics of the climate. Then the analysis of additional climate indicators obtained with the help of climate indices, which complexly represent the climate of a place, is approached. Thus, climate indices show some specifics of climate, such as the degree of continentality, oceanity, aridity, or they are used to consider the influence of weather types on the human body. A more detailed spatial distribution and variation of climate indices has been done for the northern parts of Greece (*Baltas,* 2007) and Italy (*Nistor,* 2016), as well as for the area of Turkey (*Deniz et al.,* 2011) and Pakistan (*Gadiwala et al.,* 2013). There are also other analyses in numerous studies (*Sjögersten* and *Wookey,* 2004; *Filatov et al.,* 2005; *Croitoru et al.,* 2013; *Blanka et al.,* 2013; *Andrade* and *Corte-Real,* 2015; *Araghi et al.,* 2018; *Jahangir* and *Danehkar,* 2022). There are a lot of research papers dealing with climate indices in Serbia and other countries of the Balkan Peninsula (*Vujević,* 1961; *Maćejka,* 2003; *Malinović-Milićević*, 2013; *Pecelj et al.,* 2013, 2017; *Basarin et al*., 2014, 2017; *Stojićević et al*., 2016; *Burić et al.,* 2018, 2019; *Milentijević et al.,* 2018). Climate indices have found their application in many industries, especially in forecasting agricultural production and opportunities for the development of certain types of tourism (*Dalezios et al.,* 2001; *Deniz et al.,* 2011; *Moral et al.,* 2016; *Ren et al.,* 2017; *Kamyar et al.,* 2020; *Gudko et al.,* 2021).

In the reports of the Intergovernmental Panel on Climate Change (*IPCC,* 2021) it is pointed out that Europe has warmed significantly in the last 5–6 decades. The area of Southern Europe and the Mediterranean also registers a significant trend of rising temperatures, while regional differences are observed in precipitation, but many studies indicate the presence of a negative trend and more frequent and prolonged droughts (*Komuscu,* 2001; *Gao* and *Giorgi,* 2008; *Feyen* and *Dankers,* 2009; *Koutroulis et al.,* 2010; *Tsanis et al.,* 2011; *Kjellström et al.,* 2011; *Hoerling et al.,* 2012; *IPCC,* 2014; *Karabulut,* 2015). In the Western Balkans, the region to which Serbia belongs, there is also a significant trend of rising temperatures, while annual precipitation in general had a slight negative trend (*Kurnik et al.,* 2017). Climate projections suggest that the Western Balkans could face significant climate change in the future, as the region is very vulnerable in relation to the most part of the European continent (*Lung* and *Hilden,* 2017; *IPCC*, 2021). As a result of climate change, i.e., the anthropogenic greenhouse effect, the results of projections for Serbia (*Kržič et al.,* 2011; *Djurdjevic et al.,* 2019) and the neighboring Montenegro (*Burić* and *Doderović,* 2020; *Doderović et al*., 2020; *Burić* and *Doderović,* 2021) show that in the future we can expect a reduction in precipitation and a significantly warmer climate, with more frequent extreme weather and climate events (more frequent and prolonged droughts, heavy rains, floods, etc.). Yet, *Burić* and *Stanojević,* (2020) point out that changes in cloudiness over Montenegro, and thus fluctuations in precipitation, can be largely attributed to variations in teleconnections (atmospheric and oceanic).

In the era of contemporary climate change, there is no doubt that climate indices will have an increasingly important application not only in agriculture, tourism, and other sectors of the economy, but may indicate the need for more rational water use, especially in areas where precipitation trends are registered and projected. Therefore, the aim of this paper is a more complex presentation of climatic conditions in Serbia, using geospatial analysis of the distribution and variation of four climate indices: Johansson Continentality Index (*Johansson,* 1926; *Conrad* and *Pollak,* 1951), Kerner Oceanity Index (*Kerner,* 1905; *Retuerto* and *Carballeira,* 1992; *Gavilan,* 2005; *Baltas,* 2007), De Martonne Aridity Index (*De Martonne,* 1926), and Pinna Combinative Index (*Zambakas,* 1992). For the purposes of this paper, the period 1951–2010 was used, and the indices were calculated on the basis of average monthly and annual values of temperature and precipitation from the 31 meteorological stations in Serbia. A Walter climate diagram was made, using as an example a typical representative of the climate of Serbia, and in order to see if there is a dry period in the year, based on the monthly values of temperature and precipitation. In order to determine the aridization trend, monthly data were also used to make polar diagrams for two 30-year periods (1951–1980 and 1981–2010). Thus, by applying the climate indices of continentality and oceanity, numerical differentiation is given, and the degree of influence of the mainland and neighboring sea and ocean basins (Adriatic, Mediterranean, Atlantic) on the climate of Serbia in the observed 60-year period is indicated.

The conceptual model used in this paper is that the influences of sea surfaces on continental masses are important, and their influence rate on the weather and climate of the surrounding geographical areas depends on the distance and relief characteristics. The relationship between oceanic and land surfaces is one of the most important in the Earth's climate system. It can be said that oceanity is the degree of influence of the ocean and sea surfaces on the neighboring land, which is the opposite in the case of continentality. In fact, these influences are mostly predisposed to synoptic situations during the year, i.e., they relate to the trajectories and position of cyclones and weather fronts coming from the sea, in general. In that sense, the results presented in this paper represent a kind of "synoptic" classification of climate indices in Serbia in the mesoscale.

2. Databases and methodology

2.1. Area of interest

The field of research is Serbia, a country in Southeast Europe and the Balkan Peninsula. It is a landlocked country (no access to the sea), with an area of 88361 km². The air distance between the capital (Belgrade) and the Adriatic and Aegean Sea is about 350 km, or about 500 km, while the Black Sea is about 620 km, and the Atlantic coast is over 1300 km away. The relief is lowland in the north (part of the Pannonian lowland), and in the rest of the country it has a hilly–mountainous character. The lowest point is in the east (28 m above sea level) – at the confluence of the Timok River and the Danube (tripoint of Serbia, Bulgaria, and Romania), while the mountain peaks in the south reach a height of just over 2500 m. Serbia is located almost in the middle of the northern hemisphere, i.e. between the coordinates $41^0 53'$ and $46^0 11'$N (*Fig. 1*). Latitude, relief characteristics, distance from the sea, and variations of upper air currents are the main factors that shape the climate of this country. In general, according to the Köppen climate classification, moderately warm (*C*) and moderately cold or boreal (*D*) climates are present in Serbia. Lower terrains have the characteristics of *C* climate, while mountainous areas above 1000 m above sea level are characterized by *D* climate.

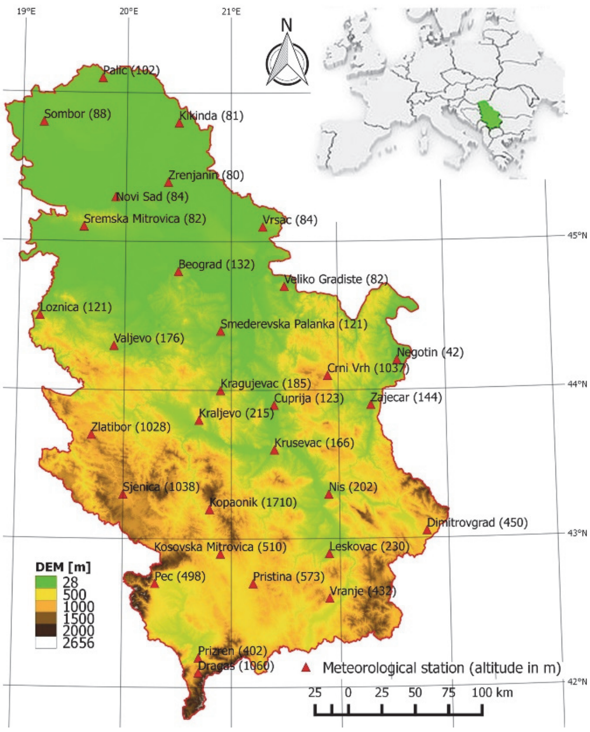

Fig. 1. Locations and altitude of meteorological stations used in the analysis.

2.2. Data

For the purposes of this research, monthly/annual data of temperature and precipitation from the 31 meteorological stations (MS), obtained from the Republic Hydrometeorological Service of Serbia, were used. Time series, for the observed 60-year period (1951–2010), were complete for 20 MS, while for 5 MS a negligible percentage of data was missing (up to 0.5%). The other 6 MS, located in southern Serbia, lacked up to 15% of the data in series (MS: Kosovska Mitrovica, Pristina, Prizren, Dragas, and Pec), mainly for the period after 2000. After visual inspection, the relative homogeneity of data sets from all MS was examined. For these purposes, the Multiple Analysis of Series for Homogenization (MASH) method, developed by the Hungarian Meteorological Service, was used (*Szentimrey,* 1999, 2003). Using MASH methods, parts of time series that did not meet the conditions of homogeneity (which were inhomogeneous) were excluded from further analysis (0.1–0.9% of data, depending on the time series). For the purposes of this paper, version MASHv3.02 was used (*Szentimrey,* 2007), which is used not only for data quality control, but also for estimating missing (and removed inhomogeneous) data in arrays. In this way, time series (data series) of temperature and precipitation for 31 MS were completed. The hypsometry of MS is as follows: 24 MS are up to 500 m above sea level (77.4%), two are at altitudes between 500 and 1000 m (6.5%), and 5 MS are at altitudes above 1000 m (16.1%).

2.3. The used methods

Based on the mean monthly values of temperature and precipitation, and the data on the latitude of the MS included in the analysis, calculations were made for the Johansson Continentality Index, Kerner Oceanity Index, De Martonne Aridity Index, and Pinna Combinative Index. The spatial distribution of the obtained results was done using the Quantum Geographic Information System (QGIS), and in order to make the maps as clear as possible, raster GIS was used.

Johansson Continentality Index (CCI). *Conrad* and *Pollak* (1951) suggested a modification of *Johansson* (1926) equation of climate classification, because the continentality index tends to infinity when tends to zero. The modified equation has the following form (climatic categories according to Conrad and Pollak are given in *Table 1*):

$$CCI = 1.7\ T_{ata}/\,sin(\phi + 10) - 14.0 \tag{1}$$

where T_{ata} is the annual temperature amplitude and φ is the station latitude in degrees.

Table 1. Climate classification according to *Conrad* and *Pollak* (1950)

Climate type	CCI
hyper–oceanic	-20 ≤ **CCI** < 20
oceanic/maritime	20 ≤ **CCI** < 50
sub–continental	50 ≤ **CCI** < 60
continental	60 ≤ **CCI** < 80
extreme/hyper–continental	80 ≤ **CCI** ≤ 120

Kerner Oceanity Index (KOI). Assuming that in a maritime climate, autumn is a little warmer than spring, *Retuerto* and *Carballeira* (1992), *Gavilan* (2005), and *Baltas* (2007) define the Kerner Oceanity Index by the following formula (categorization of climate according to KOI values is given in *Table 2*):

$$KOI = 100\ (T_{oct} - T_{apr})/T_{ata}, \tag{2}$$

where T_{oct} and T_{apr} are the average monthly temperature in October and April, respectively.

Table 2. Climate classification according to *Kerner* (1905)

Climate type	KOI
hyper–continental	**KOI** ≤ -10
continental	-10 < **KOI** ≤ 0
sub–continental	0 < **KOI** ≤ 10
oceanic	10 < **KOI** ≤ 20
hyper–oceanic	20 < **KOI** ≤ 50

De Martonne Aridity Index (I_{DM}). There are several aridity indices used in climatology, the most famous being the De Martonne Aridity Index (*De Martonne,* 1926), which was also applied in this research. De Martonne's climate classification is based on the duration of drought during the year, and this aridity-humidity index is defined as the ratio of average annual precipitation (R) and temperature (T) values increased by 10 °C (the climate classification according to De Martonne is given in *Table 3*):

$$I_{DM} = R/(T + 10) \ . \tag{3}$$

Table 3. Climate classification according to the De Martonne Aridity Index

Climate type	**I_{DM}**	**Annual precipitation (mm)**
dry	$I_{DM} < 10$	$R < 200$
semi–dry	$10 \leq I_{DM} < 20$	$200 \leq R < 400$
Mediterranean	$20 \leq I_{DM} < 24$	$400 \leq R < 500$
Semi–humid	$24 \leq I_{DM} < 28$	$500 \leq R < 600$
humid	$28 \leq I_{DM} < 35$	$600 \leq R < 700$
very humid	a) $35 \leq I_{DM} \leq 55$ b) $I_{DM} > 55$	a) $700 \leq R < 800$ b) $R > 800$

Pinna Combinative Index (Ip). Pinna has developed a combinative index (*Zambakas,* 1992; *Baltas*, 2007; *Deniz et al*., 2011), which has the following form:

$$I_P = 1/2/(I_{DM} + 12R_d/T_d + 10) \ , \tag{4}$$

where R_d and T_d are the mean values of precipitation and temperature of the driest month and *Ip* is used to indicate drought-prone regions that need irrigation. The modified climate classification according to the Pinna Combinative Index is shown in *Table 4.* The modification was performed by the author in order to adapt the climate classification categories to the temperate climate in which Serbia is located.

Table 4. Modified climate classification according to the Pinna Combinative Index by the author

Climate type	I_P	Type of vegetation
arid	$Ip < 10$	not specified
semiarid Mediterranean	$10 \leq Ip \leq 20$	formal Mediterranean
modified Mediterranean	$20 < Ip \leq 30$	sub Mediterranean
humid continental	$30 < Ip \leq 44$	mixed forests and steppes
perhumid continental A	$44 < Ip \leq 80$	coniferous forests
perhumid continental B	$Ip > 80$	coniferous forests and tundra

2.3.1. Procedure of creating raster maps using QGIS 2.8.1.

The spatial distribution of the obtained results was done using the Quantum Geographic Information System, version 2.8.1 (*QGIS 2.8.1*). In order to make the maps as clear as possible, raster GIS was used. Data from 31 weather stations were used to create the raster. Latitude (φ), longitude (λ), and altitude (h) of MS were used as a predictor variable to create a regression model based on which the interpolation of temperature/precipitation was done. Further, based on the *Shuttle Radar Topography Mission (SRTM)* and *Digital Elevation Model (DEM),* at a resolution of 30x30 m, the mean and standard deviation of slope and terrain exposure were calculated from circular zones with a diameter of 10 km that were formed around the stations. Due to the later phases of the work, two auxiliary rasters were formed for φ and λ. The choice of predictors was made based on the significance they have in the regression model. It turned out that in the case of precipitation, the highest percentage of variance affects combinations λ, h, and the mean values of the slope of the terrain around the station. Considering the temperature, the highest percentage of the variance covers h and φ.

The next step was to divide the dataset into a subset for interpolation (27 stations) and a subset for testing the accuracy of modeled temperature and precipitation values (4 stations, mostly evenly distributed from north to south: Vrsac, Cuprija, Leskovac, Smederevo). In the subset for interpolation, new values of temperature and precipitation were formed 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. A separate layer was made out of these new values of temperature and precipitation, using simple kriging, which was then transferred to a raster shape. Multiplying the coefficients from the regression model by the corresponding rasters (*DEM*, auxiliary rasters for φ and λ) and by adding to the previously formed temperature and precipitation rasters, raster maps were obtained.

The accuracy of the applied approach was verified by comparing the temperature/precipitation values, with the cells from the subset for testing and the pixel values in which the stations are located. The difference between such modeled and observed values is expressed through *mean absolute error (MAE)* and *root mean square error (RMSE)*, and the obtained results are shown in *Table 5*.

Table 5. Mean absolute error (MAE) and root mean square error (RMSE) of the modeled air temperature and precipitation values for all three series (1951–1980, 1981–2010, and 1951–2010)

	Error	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Temperature														
1951–1980	RMSE	0.6	0.3	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
	MAE	0.5	0.3	0.4	0.5	0.6	0.5	0.5	0.5	0.5	0.4	0.5	0.5	0.5
1981–2010	RMSE	0.6	0.5	0.5	0.5	0.5	0.3	0.5	0.4	0.5	0.7	0.9	0.5	0.5
	MAE	0.5	0.4	0.4	0.3	0.3	0.2	0.3	0.4	0.4	0.5	0.7	0.5	0.4
1951–2010	RMSE	0.9	0.5	0.5	0.5	0.4	0.3	0.3	0.4	0.5	0.6	0.7	0.9	0.5
	MAE	0.8	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.7	0.4
Precipitation														
1951–1980	RMSE	6.1	8.6	7.8	4	3.6	4.1	6.7	5.9	6.7	7.5	3.9	6.4	55.4
	MAE	5.8	7.8	6.5	2.9	3.2	3.3	6.3	5.4	6.6	7.2	3.6	5.5	49.9
1981–2010	RMSE	7.9	6.6	7.8	6.4	2.6	6.9	2.9	3.1	3.8	7.6	7.7	5.1	56.6
	MAE	6.9	5.3	7.8	4.1	2.0	5.9	2.3	2.7	3.2	7.3	7.1	4.9	56.3
1951–2010	RMSE	6.0	5.6	7.0	3.8	2.5	4.4	3.7	3.4	4.9	6.6	5.8	5.7	54.4
	MAE	5.8	5.5	6.9	2.9	2.2	3.5	3.1	3.3	4.7	5.7	5.5	5.4	53.0

The whole procedure was performed in *QGIS 2.8.1,* while the softwares *R* and *STATISTICA 8* were used to form the regression model and calculate the errors. Only the *Inverse Distance Weighted (IDW)* geostatistical interpolation method was used to create maps of the Pinna Combinative Index and Johansson Continentality Index. This geostatistical interpolation method was used due to the complexity of the Pinna Combinative Index (Johansson Continentality Index) formula, which takes into account precipitation and temperature of the driest month, and the driest month is not the same at each meteorological station in Serbia.

3. Results and discussion

The first part of the results provides an analysis of the spatial distribution of precipitation and temperature in Serbia. The second part will present the results of the considered climate indices.

3.1. Spatial distribution of average annual precipitation and temperature in Serbia

The average annual rainfall in Serbia, calculated for the period 1951–2010, varies a lot. The highest amount of precipitation is registered in the southwestern and western parts of the country (827.4–1134.1 mm), and the lowest in the northeastern and northern parts (520–600 mm). In the average year, the difference in precipitation between the wettest and the driest place is 613.4 mm. In general, it can be concluded that precipitation is decreasing from the southwest and west to the northeast and east of the country (*Fig. 2a*). Differences in the amount of precipitation in Serbia are due to relief dissection and the influence of cyclonic circulation. Namely, the southwestern and western parts of Serbia (areas richest in precipitation) are much more often affected by the periphery of cyclone activity from the south (when the center of the cyclone is above the Adriatic or when the so-called Genoa cyclones are active), while the northern parts remain out of reach. When it comes to temperature, the average annual values for the period 1951–2010, range from 1.0 °C in the higher mountain areas to 11.7 °C in the plains and valleys of Serbia (*Fig. 2b*). In general, the temperature decreases from lowland areas in the north to the mountainous areas in the south.

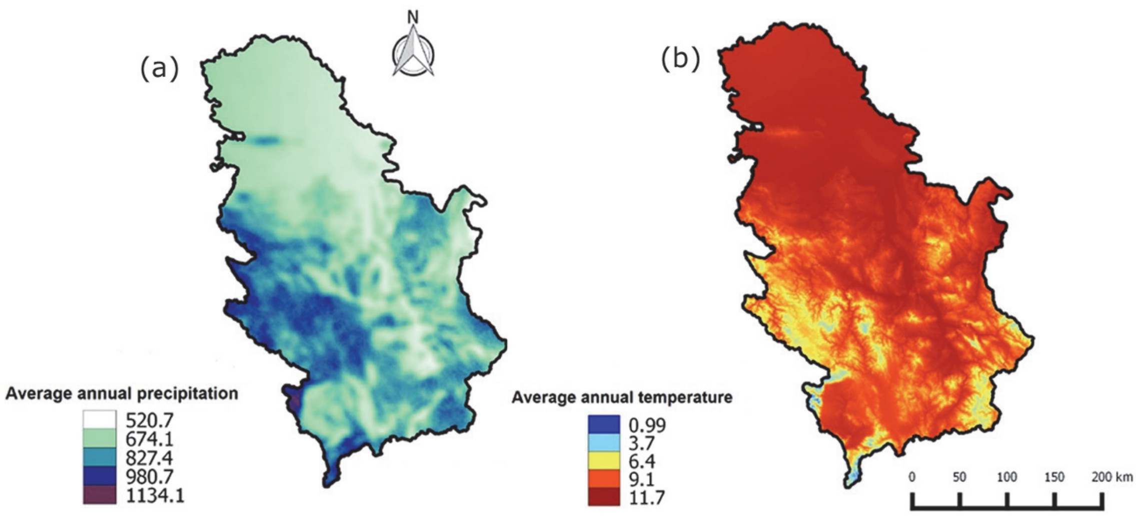

Fig. 2. Average annual values of precipitation (a) and temperature (b) in Serbia for the period 1951–2010.

3.2. Spatial distribution of climate indices

Analysis of the Johansson Continentality Index (*CCI*), which indicates the degree of continentality, showed that its values range from 23.1 (MS Kopaonik) to 34.8 (MS Negotin). Thus, the absolute difference of *CCI* in Serbia, for the period 1951–2010, is 11.7, which speaks in favor of how the climate under the influence of general synoptic schemes above Serbia is diversified in a relatively small area. The lowest values of this index are distributed mainly on the stations in western and southwestern Serbia, which are more influenced by maritime air masses. Moreover, all categories of climate types according to the *CCI* index in Serbia (*Fig. 3a*) belong to the oceanic/maritime climate with varying degrees of this effect. The minimum values of the *CCI* index occur at mountain stations at higher altitudes, which is in line with the laws of general synoptic schemes over Serbia. The maximum values of the *CCI* index indicate the more continental parts of Serbia, namely the northeastern and northern parts (the edge of the Pannonian Plain). The average value of *CCI* for the entire territory of Serbia is 30.7 and indicates that the climate of this country is oceanic/maritime, in general.

However, the values of the Kerner Oceanity Index (*KOI*) indicate that both continental and oceanic climates are present in Serbia. This is in line with the geographical position, the influence of relief elements, and variations in synoptic conditions over Serbia. The values of this index vary from -2.5 (MSNegotin) to 17.6 (MSKopaonik). According to the values of *KOI*, MSs in the northeast and north (Negotin, Zajecar, Sremska Mitrovica, Sombor, and Palic), i.e., parts of the country that are less influenced by maritime air masses from the Adriatic and Mediterranean, have the highest degree of continentality in Serbia. On the other hand, MSs located in higher mountain areas in the southwest and south, i.e., parts of Serbia that are closer to the Adriatic and Mediterranean, have the highest amounts of precipitation in the country and the highest values of *KOI* (*Fig. 3b*). In support of the fact that maritime and continental influences intertwine in Serbia is the average value for the entire territory of the country, which is 1.75.

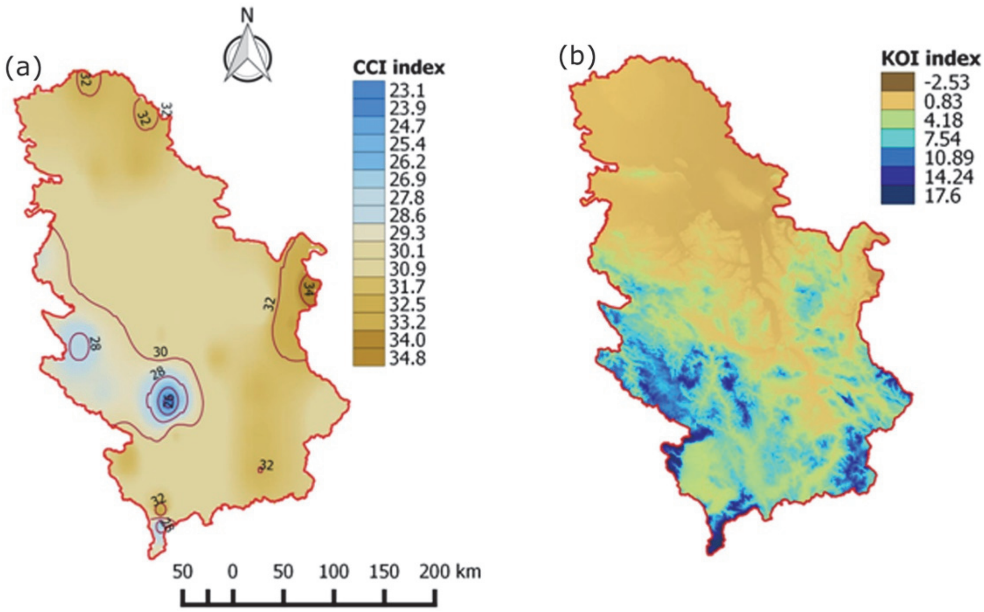

Fig. 3. Spatial distribution of the Johansson Continentality Index according to *Conrad* and *Pollak* (1951) (a) and the Kerner Oceanity Index (b) for the period 1951–2010.

The values of the two previous indices (*CCI* and *KOI*) largely correspond, which shows a statistically significant correlation and coefficient of determination, which is $r^2 = 0.69$ (*Fig. 4*). However, if the results of *CCI* and *KOI* were to be evaluated, it would be concluded that the Kerner Oceanity Index (*KOI*) is more appropriate for the territory of Serbia, regardless of the fact that the classification distinguishes only two categories (continental and maritime climates).

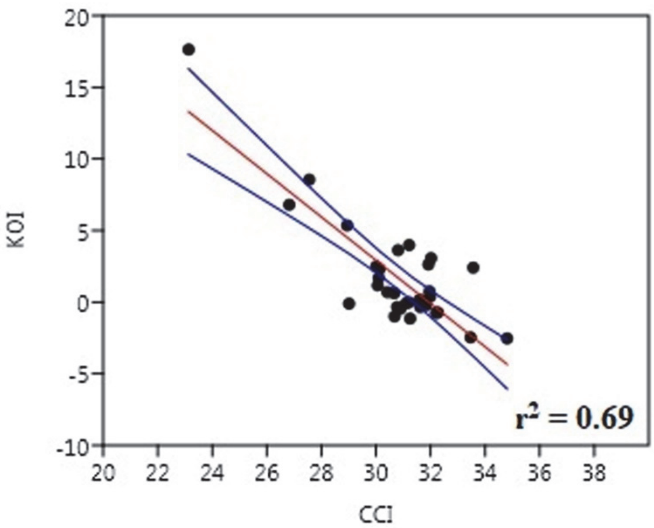

Fig. 4. Statistical analysis between the *CCI* index and the *KOI* index for the period 1951–2010 (blue lines indicate a 95% confidence interval).

One of the most frequently used indicators of aridity is the De Martonne Aridity Index (I_{DM}). For the period 1951–2010, I_{DM} ranges from semi-humid values in the northern part of the country (min. 26.7) to a very humid climate in the southern part of Serbia (max. 72.8). Therefore, the values of this index are gradually increasing from the northern, northeastern, and eastern parts of Serbia to the western, southwestern, and southern parts (*Fig. 5*), which is in line with the spatial distribution of precipitation. In other words, on the annual level, the degree of aridity increases from the southwest and west to the northeast and north of Serbia. When observing the entire period (1951–2010), the average value of the aridity index for the territory of Serbia is 34.7, i.e., it is on the border of the semi-humid and humid climates.

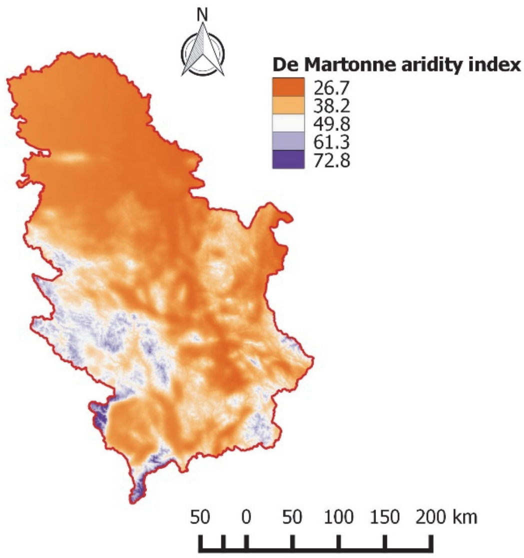

Fig. 5. De Martonne Aridity Index in Serbia for the period 1951–2010.

According to climate models, in the conditions of contemporary climate change in the area of Southeast Europe, i.e., the Balkan Peninsula, and thus in Serbia, an increase in aridity should be expected. To verify this, the years were categorized according to the I_{DM} values for the two subperiods 1951–1980 and 1981–2010. The results showed that the frequency of years belonging to the classes very humid and humid did not change significantly during the two observed periods. However, the frequency of years with semi-humid characteristics in the first 30-year period (1951–1980) was 3 years (10%), and in the second period (1981–2010) it was doubled (20%). This means that the climate of Serbia in the second 30-year period, observed on an annual basis, has become more arid (*Table 6*), which is a consequence of a significant trend of increasing average annual temperatures, because no significant changes are observed in precipitation. In any case, the previous analysis clearly identified the signal of climate change in Serbia, which can be linked to global warming and the problem of aridity in Southeast Europe in general.

Table 6. Annual frequency according to the De Martonne Aridity Index (I_{DM}) climate classification for the periods 1951–1980 and 1981–2010

Climate type	I_{DM}s	1951–1980 Frequency	1951–1980 Frequency (%)	1981–2010 Frequency	1981–2010 Frequency (%)
dry	$I_{DM} < 10$	0	0	0	0
semi-dry	$10 \leq I_{DM} < 20$	0	0	0	0
Mediterranean	$20 \leq I_{DM} < 24$	0	0	0	0
semi-humid	$24 \leq I_{DM} < 28$	3	10	6	20
humid	$2 \leq I_{DM} < 35$	18	60	16	53.3
very humid	$35 \leq I_{DM}$	9	30	8	26.7

In order to determine in more detail the climatic characteristics in Serbia, the Pinna Combinative Index (*Ip*) for the period 1951–2010 was calculated (*Fig. 6*). At all meteorological stations included in the analysis, the values of this index ranged over 20, which means that the climate is humid, in general. Therefore, according to the values of Ip, the arid and semiarid Mediterranean climate is not present in Serbia, which is in line with the geographical position of Serbia and the dominant physical-geographical factors.

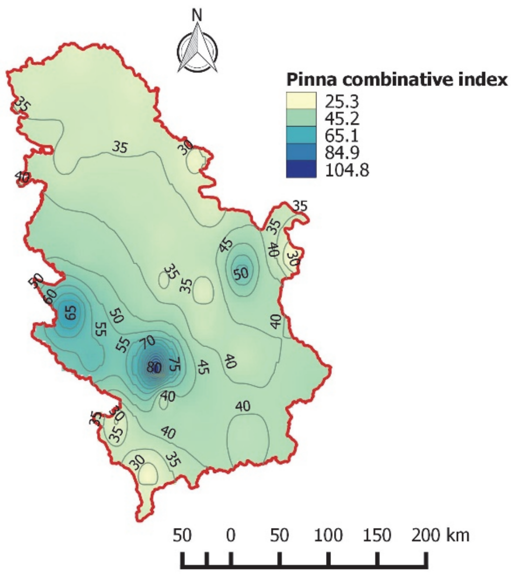

Fig. 6. Pinna Combinative Index in Serbia for the period 1951–2010.

The obtained value of *Ip* (25.3–26) belonged to the class of modified Mediterranean climate (semiarid climate) only for two MSs (Negotin and Prizren), and this can be related to smaller annual precipitation amounts and pluviometric regime. In the higher mountain areas, i.e. in the places that register the highest precipitation, *Ip* values go up to 104.8 (MS Kopaonik), so that the western and southwestern parts of Serbia have the characteristics of perhumid continental A and B climate. The average value of *Ip* for the entire territory of Serbia is 39.8, which corresponds to the humid continental climate in which mixed forest and steppe vegetation dominate.

In any case, the territory of Serbia is outside the Mediterranean (semiarid) climate, but it should be noted that the two mentioned localities are close to this type. The influence of the Mediterranean reaches the southern parts of the country (MS Prizren – parts of the country closest to the Adriatic and Aegean Sea), while in the northeast (MS Negotin), there is less rainfall, as well as in northern Serbia, but these areas cannot be meteorologically linked to the Mediterranean climate in climatic-vegetation sense.

The spatial distribution and variation of I_p and I_{DM} in Serbia is quite similar, which is confirmed by the high value of the coefficient of determination of r^2 = 0.78 (*Fig. 7*). The limit value of the De Martonne Aridity Index of 28 (humid climate) coincides with the Pinna Combinative Index greater than 20 (all values > 20 indicate the humidity of the climate). However, when it comes to isolating the arid or humid climate of MS included in the analysis, evaluating the results of these two indices, we believe that I_{DM} can be preferred over I_p.

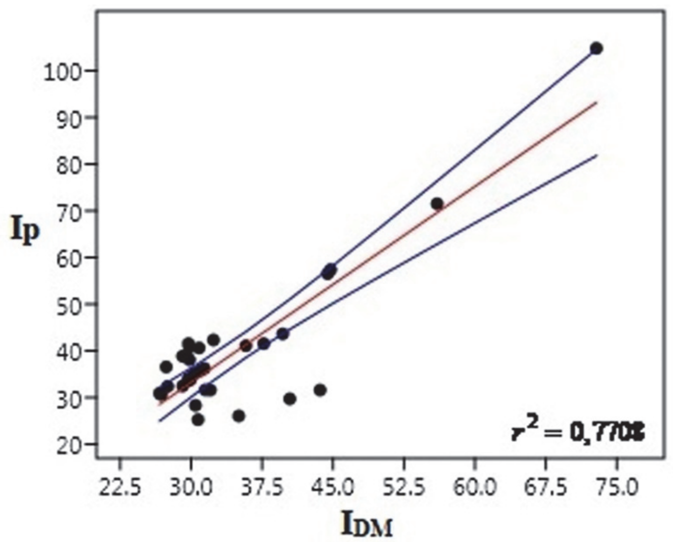

Fig. 7. Statistical analysis between the De Martonne Aridity Index (I_{DM}) and the Pinna Combinative Index (I_p) for the period 1951–2010 (blue lines indicate a 95% confidence interval).

3.3. Climate analysis on a monthly basis

In order to conduct an analysis on a monthly basis and to be efficient, one MS was chosen as a typical representative of the dominant climate in Serbia. The decision that it should be MS Kragujevac is due to the fact that it is located almost in the geographical center of Serbia and at an altitude of less than 500 m (about 65% of the territory of Serbia has an altitude of up to 500 m). We first constructed a Walter climatic diagram, specificity of which is that the curves of temperature and precipitation are in a certain ratio (1:2, 1:3, and 1:10), in order to highlight dry and/or rainy periods. (*Walter et al.*, 1975). In Kragujevac, in general and in most of Serbia, during the colder part of the year (October–March), the amount of precipitation is lower than in the warmer half (April–September). The month, in which the ratio of precipitation (R) and temperature (T) is 1:2 ($R < 2T$) on the diagram is dry, and semi-dry when the ratio is $2T < R < 3T$. The graph clearly shows that the dry season lasts from July to September, in general (*Fig. 8*).

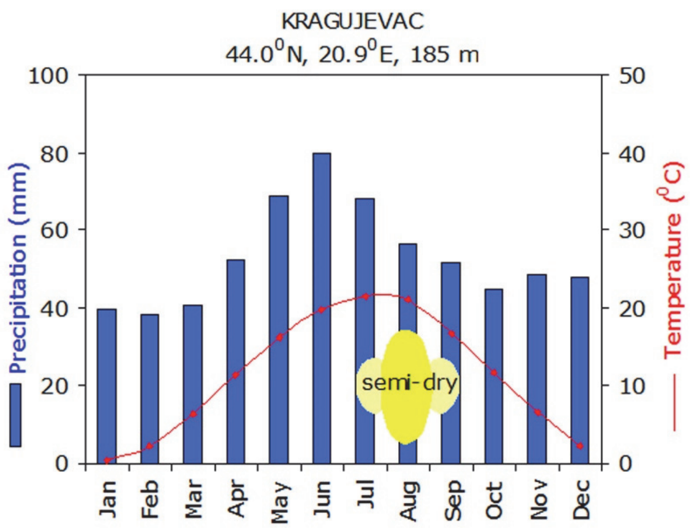

Fig. 8. Climate diagram of temperature and precipitation for MS Kragujevac (1951–2010).

The polar diagrams show the average monthly values of precipitation (*Fig. 9a*) and temperature (*Fig. 9b*). When it comes to precipitation, it is noticed that the monthly amounts range from 40 mm (February) to 80 mm (June). Comparing two simultaneous periods (1951–1980 and 1981–2010), it can be concluded that in the second 30–year period there was a decrease in precipitation in the period when water is most needed by vegetation (May–June–July) and an increase in temperature, especially in the warmer part of the year (May–August). The facts that the dry season lasts from July to September (Walter climate diagram), i.e., in the warmer part of the year when the need for water is higher, and that in the second 30–year period there was an increase in temperature and a decrease in precipitation during the vegetation period, clearly indicate the tendency towards more arid conditions in Serbia.

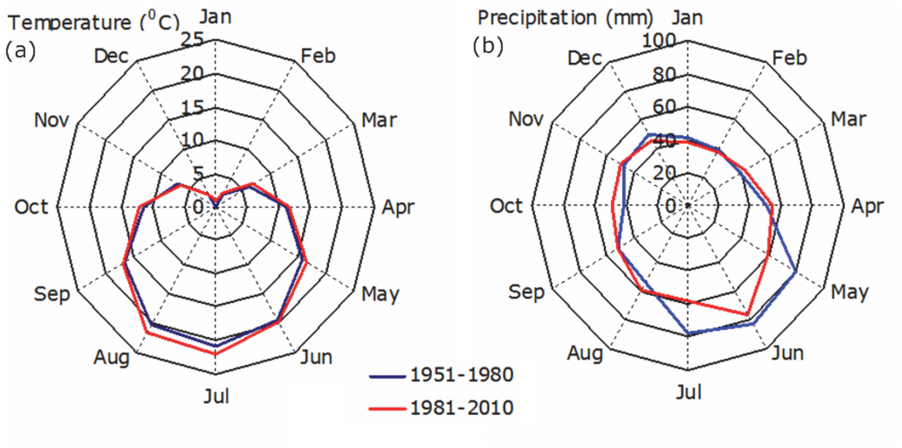

Fig. 9. Polar diagram of precipitation (a) and temperature (b) for MS Kragujevac, for the periods 1951–1980 and 1981–2010.

4. Conclusion

In order to define the climate in more detail, i.e., the degree of continentality and oceanity, the paper presents the spatial distribution of climate indices on the territory of Serbia, and the results are presented in the form of appropriate thematic maps. Based on data from 31 MSs for the period 1951–2010, the classification of climate continentality using the *CCI* index is in line with the climate classification based on the *KOI* index. This is confirmed by the high correlation between the mentioned indices of continentality and oceanity, i.e., similar spatial distribution and variation. The effect of continentality was discovered on most MS in Serbia, while the effect of oceanity was discovered on the MS located in the southwestern and western hilly and mountainous part of Serbia. This can be attributed to general synoptic patterns over Serbia during a multi-year period.

Climate classification according to the De Martonne Aridity Index (I_{DM}) and the Pinna Combinative Index (I_p) has been made also, and the results obtained are largely compatible. This is also shown by the conducted statistical analysis of the coefficients of determination, which were high and indicated a similar spatial distribution and variation. However, a more precise classification of Serbia's climate is provided by the I_{DM}. According to the results obtained by I_p, it is evident, that there is no arid and semiarid Mediterranean climate on the territory of Serbia, which is in line with the geographical position and physical-geographical conditions prevailing in this country (primarily synoptic conditions and relief characteristics). According to the results of the I_{DM}, there are no dry and semi-dry Mediterranean climate zones on the territory of Serbia. The range of I_{DM} climate categories varies from semi-humid to very humid climates. The Walter climate diagram indicates that it is dry in the warmest, and arguably the most unfavorable part of the year. This circumstance (dry period in the warmest part of the year, when the need for water is increased), as well as the fact that in the second 30–

year period (1981–2010), higher temperatures and lower precipitation are registered, as it is shown by polar diagrams for Kragujevac, a typical representative of the climate of Serbia, indicate that the climate of this country is becoming more arid, in general. The results of this study could be of application significance in many areas of human activity, especially in the applied branches of agriculture, tourism, and water management.

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