THERMAL REGIME OF THE KRAGUJEVAC BASIN

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Abstract: Thermal regime, as a measure of thermal conditions, is used for better climate characterization and it is an integral part of the overall climate characteristics of a specific geospatial. Thermal characteristics of the Kragujevac Basin were determined by using measurement data from the only higher order station, MWS Kragujevac, for the period from1981 to 2010. The analysis includes mean monthly air temperatures, extreme and absolute temperatures, incidence of typical days, as well as the linear trend of the mean annual air temperatures. Other than the method of analysis, comparative method and the method of linear regression were also employed in processing statistical data.

Based on the presented data, it can be concluded that Kragujevac and its surroundings belong tothe thermal continental climate regime, which is indicated by the mean annual temperature amplitude. This fact is additionally supported by the thermodromic coefficient by Kerner.

Another fact of a great importance is that the mean annual temperatures increase trend is pronounced which is explained as an influence of the urban environment on the temperature regime.

Key words: thermal regime, air temperature, Kragujevac Basin, comparative method, method of the linear regression

1. Introduction

Kragujevac Basin is a smaller tectonic-fluvial extension of the compound valley of Lepenica. General geomorphological depiction was presented by Ž. Stepanović (1966) who regarded its relief in a strict sense i.e. to the drainage divide between Lepenica and Gornja Rača.

The Basin also continues over the drainage divide as a complete negative morphostructure so the valleys of Jasenica and Gornja Rača are its morphological borders in NW. Proceeding from the morphology, Kragujevac Basin has more characteristics of a valley. Its axis (30 km), positioned between the valley of Jasenica (in the NW) and the peak of Žeželj (in the SE), is almost twice as long as its transverse axis, between Majdan (in the SW) and crystalline peak of Prnjavor-Šupljaja-Gradište (in NE) which is 16 km long (Zeremski, 1983).

Valley area of the Great Morava, which is connected to the Kragujevac Basin, is opened to the North because of the impact of the local orographic conditions. Namely, cold air masses from the northern quadrant, which often penetrate from the Pannonian Plain over the valley of the Great Morava, have considerable influence on the climate characteristics of the researched territory, primarily on the thermal regime (Milosavljević, 1969).

Thermal characteristics of the Kragujevac Basin were not elaborated in detail in the literature. First of all, they were discussed as a part of the research on Serbian climate (Radinović, 1966; Rakićević, 1980; Ducić et al, 2005) and as part of the research on the valley of the Great and South Morava (Milosavljević, 1969). For the reasons mentioned, we have decided to give detailed and versatile explanation on air temperature characteristics of the Kragujevac Basin.

2. Material and method

Thermal charcteristics of Kragujevac and its surrounding were calculated according to the data from the station of the first order, MWS Kragujevac (φ=44º02´N; φ=20º56´E; Hs=185 m), for the period from 1981 to 2010. They were calculated by the statistical, graphical and comparative method. Those methods were used to analise: mean monthly air tmperatures, mean maximum and minimum air temperatures, and incidence of typical days and the mean annual air temperature change trend was calculated by the method of linear regression.

3. Results

Mean Monthly Air Temperatures

The city of Kragujevac and its surroundings are located in the region of temperate latitude and they belong to the temperate zone climate. That is why maximum and minimum temperature can be distinguished in the movement of the annual air temperature i.e. it shows certain regularities (Chart 1). Namely, the temperature increases regularly from January to July when it reaches its maximum (21,9ºC),that is to August and then it decreasesregularly to January when it reaches its annual minimum (0,9°C). There is a noticeable temperature jump in March, which indicates the beginning of the warmer part of the year, which coincides with the beginning of the growing season. The annual air temperature amplitude is above 20°C (21,0ºC).

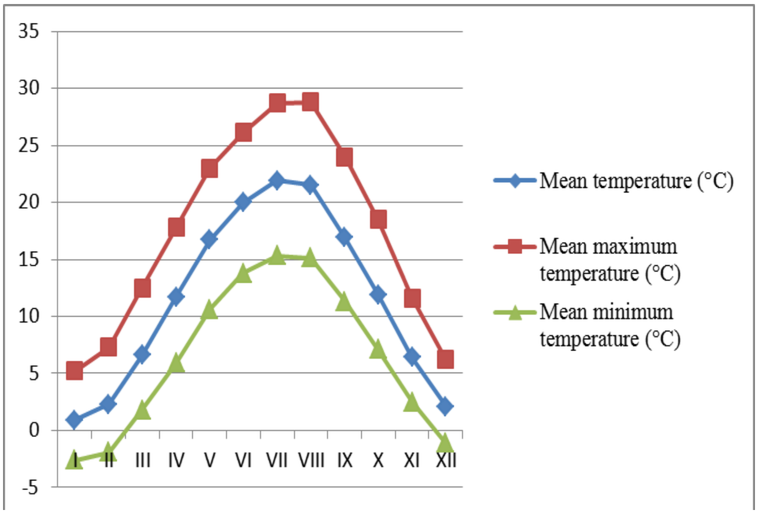

Chart 1–Mean monthly, mean maximum and mean minimum air temperatures in Kragujevac (1981-2010)

The extreme annual temperatures flows behave almost identically as the mean annual temperatures. The highest mean maximum temperature is not in July, but it has shifted to August (28,8°C), while the lowest mean temperature remained in January (-2,6ºC). Mean annual maximum temperature is 17,5°C. In the flow of the mean annual maximum temperatures it is also possible to observe negative values during three winter months. The lowest mean minimum temperature in January is (-2,6ºC), and the highest in July(15,3°C). Temperature in August is similar to the one in July(15,1ºC). Mean annual minimal temperature is 6,5ºC.

Based on the mean monthly temperatures, mean temperatures of the seasons were also calculated (Table 1).

Table 1 - The mean temperature of the seasons in Kragujevac (1981-2010)

Season	Spring	Summer	Autumn	Winter
Tsr (°C)	11,2ºC	21,1ºC	11,7ºC	1,8ºC

Mean winter and summer temperatures are extremely high while the spring and autumn (transitional seasons) temperatures are more equable.

The presented mean air temperature values and the annual temperature amplitude of the Kragujevac Basin specify moderate continental climate (the amplitude is between 20-22 ºC) (Krstić et al, 2002). However, there are many equations which are used to determine more precisely the character of continentality.

One of the equations, that is often applied, is the one by F. Kerner which calculates theso-called thermodromic coefficient. Kerner completes the equation with the so-called relative thermodromic coefficient, which eliminates impact of the latitude. That gives advantage to Kerner's model over the models of other authors (Gorzynski, Cenker).

This coefficient is calculated by the formula:

$$\mathbf{K=[(Tx\text{-}Tiv) : A] * 100\ (\%)},$$

where **Tx** means monthly temperature in October (11,9°C), **Tiv** means monthly temperature in April (11,7°C), **A** is an annual temperature fluctuation (21,0°C). October and April are taken into account because their mean values are the closest to the mean annual air temperature. Mean April temperature is higher for 0.1°C and the mean October temperature is higher for 0.3°C, comparing to the annual climate normal (11.6°C). If K>15%, climate is maritime in that region. In a region of the continental climate K<15%; the lower the K is from 15%, the higher the degree of continentality is. If the continentality is fairly pronounced the coefficient has a negative sign (Vujević P., 1956).

Relative thermodromic coefficient is calculated according to the equation:

$$\mathbf{K' = [(Tx\text{-}Tiv) : \alpha] * 100\ (\%)},$$

where **α** is a relative amplitude of the annual temperature fluctuation which is calculated according to the formula **α = A:sinφ,** when A is an annual temperature fluctuation (21.0°C), **φ** is the MWS Kragujevac latitude (φ=44º02' N).

Thermodromic coefficient in the region of Kragujevac Basin is under the limit of 15% which separates maritime areas from the continental areas. It is **1.0%** and it indicates moderate continental climate while the relative thermodromic coefficient is **0.7%** and indicates more pronounced continental influence.

Absolute Temperatures

Analysing absolute temperatures, we reached a conclusion that air temperatures in the Kragujevac Basin are extremely low and extremely high (Table 2).

Table 2 – Absolute maximum and absolute minimum air temperatures in Kragujevac (1981-2010)

	I	**II**	**III**	**IV**	**V**	**VI**
max	31.01.2002. 20,6°C	25.02.2008. 24,2°C	25.03.2001. 29,4°C	30.04.2003. 31,4°C	28.05.2008. 35,4°C	26.06.2007. 39,4°C
min	**31.01.1987. -27,4°C**	14.02.1985. -23,8°C	01.03.2005. -18,3°C	09.04.2003. -5,8°C	08.05.1983. 05.05.1994. 05.05.2000. 1,4°C	10.06.2005. 4,1°C
	VII	**VIII**	**IX**	**X**	**XI**	**XII**
max	**24.07.2007. 43,9°C**	11.08.1994. 40,4°C	15.09.1987. 37,4°C	01.10.1991. 32,6°C	01.11.1990. 27,6°C	17.12.1989. 08.12.2010. 21,0°C
min	28.07.1987. 7,2°C	29.08.1981. 4,6°C	09.09.1991. 1,6°C	28.10.1991. -6,6°C	26.11.1988. -11,8°C	21.12.2009. -20,6°C

Absolute maximum temperature has been recorded on July 24, 2007 and it was 43,9°C. 2007 was well known for significantly high temperatures. From July 18 to July 24 of the said year, so for seven days in a row, the air temperature was over 40 Celsius degrees and then on July 24 it reached the absolute maximum for the observed period.

When it comes to absolute minimum temperatures, extremely low temperatures could also be recorded during the observed period. The absolute minimum temperature was recorded on January 31, 1987, it was -27,4°C. Absolute minimum was lower than 20°C during February too, it was (-23,8°C).

Absolute fluctuation is large and it is 71,3°C. There are other temperatures during the year within the absolute extremes. Negative extremes occur from October (-6,6°C) to April (-5,8°C) and they are manifested as an early or late frost.

Characteristic Days

When considering climate it is of a great importance to know the number of days with extreme temperatures which have certain limit value in a month or a year. Being familiar with these climatic parameters makes the picture about temperature conditions of the studied territory complete. For this occasion we have analysed frosty days (Tmin< 0°C), tropical days (Tmax> 30°C), cold days (T max< 0°C) and summer days (T max > 25°C - Chart 2).

Frosty days are those in which minimum air temperature is lower than 0°C. During summer we do not have frosts. Early frosts occur rarely in October (2 days). There is an increased incidence of frosty days with the beginning of November (8 days). Generally, frosty days are commonplace in the winter part of the year. Period of frost ends in April (2 days) and the highest number of frosty days occur in the coldest month, January (20 days). The average number of frosty days decreases from February (17 days) to spring months. The average number of frosty days is 76 days with frost.

Tropical days are the days in which maximum temperature is higher than 30°C. They typically occur in the warmest part of the year. They can appear from May to September and have a negative influence on vegetation because they cause longer or shorter dry periods. July and August are the months with the most increased incidence of tropical days (13 days). It was recorded that on average there are 38 tropical days during the referent period.

Cold days are those days in which the minimum temperature is lower than 0°C. The most increased incidence of cold days is in late autumn, especially December (4.6 cold days) and in winter months – January (6.1 cold days) and February (3.6 cold days). On the territory of the Kragujevac Basin there were 15 cold days in total.

Air temperature is one of the characteristics of summer days which has to be (even for a moment) equal or higher than 25°C during 24 hours period. Maximum incidence of summer days is during summer (in July 24.5 days and in August 24.8 days). Interesting fact is that summer days also occur in early spring and late autumn. Within incidence of the days with specific temperatures, it was the highest annual number of summer days that were recorded; even 99 days whose temperature is equal or higher than 25°C.

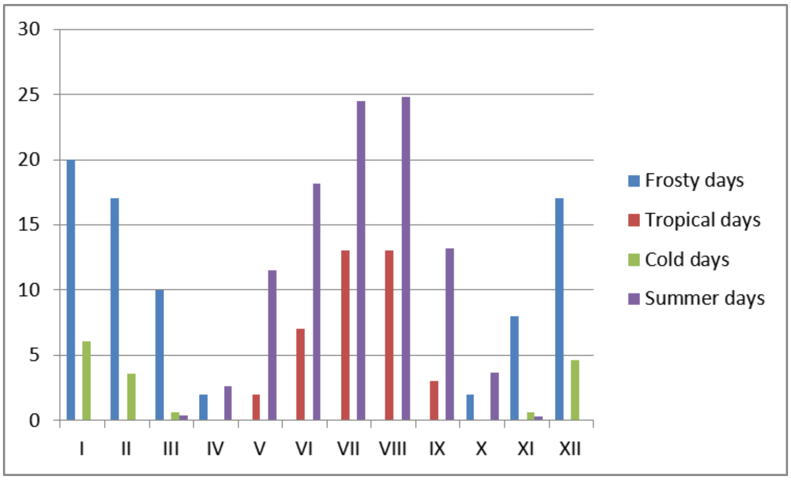

Chart 2 – Incidence of characteristic days in Kragujevac (1981-2010)

Mean Annual Air Temperatures

Based on the mean annual air temperature of the Kragujevac Basin for the period from 1981 to 2010, it was calculated the average mean annual air temperature of 11.6°C which can be registered as so called climate normal. However, although the subject is the climatic normal, the influence of the "urban heat island" which is closely connected to the population growth, a parameter which reflects the very size of the city is obvious (Unkašević, 1994).

This assertion can be proved by applying the method of regression analysis. Regression analysis represents a statistic procedure which puts two phenomena into causal relationship. Studying of the two phenomena variability is performed as a part of the analysis. One of them occurs as an independent variable and the other represents a dependent variable value. A display like this is called dispersion or scatter diagram. Points on the diagram can be completely scattered (there aren't any connection between the phenomena) or they can be arranged in a strictly defined order. Line of regression represents the line which goes through the points on the dispersion diagram and in this particular case it is a straight line (Savić et al, 2015).

General form of the linear equation is:

$$y=ax + b,$$

where **x** is an independent variable, **y** is a dependent variable, **a** is a constant in a linear equation and **b** is the linear regression coefficient. The goal of the linear regression method is to predict values for the certain **x** values. Based on the statistic data for the time interval (1981-2010) function has the following form: **y=0,0509x + 10.831** (Chart 3). In the linear trend equation **y** is a mean annual air temperature; **x** is a time interval (30 years), **b**-linear regression coeficient (Gavrilov et al, 2017). Based on the magnitude (change) of the trend ***Δy*** (°C) it can be determined positive or negative trend, according to the next equation:

$$\Delta y = y_2 - y_1;\ y_2 = 0{,}0509 * x + 10{,}831;\ y_2 = 0{,}0509 * 30 + 10{,}831;$$
$$y_2 = 1{,}527 + 10{,}831;\ y_2 = 12{,}358;\ \Delta y = 12{,}358 - 10{,}831;\ \mathbf{\Delta y = 1{,}5°C}$$

Solving the equation we can realize that the mean annual air temperature trend for the analyzed period is positive. Average deviation of the mean annual air temperatures from the climatic normal of 11,6°C is **1,5°C**.

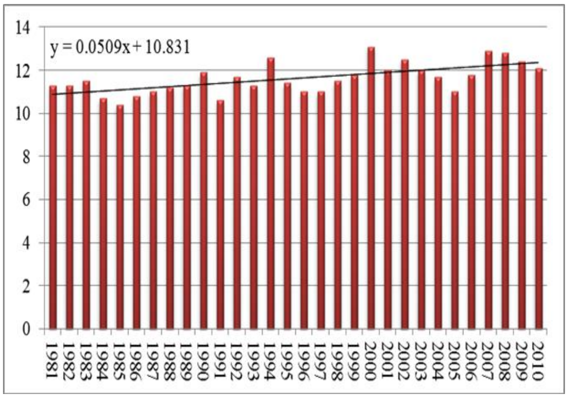

Chart 3 – Linear trend of the mean annual air temperature change and the line of regression in Kragujevac (1981-2010)

4. Discussion

Annual flow of, air temperature in the region of Kragujevac Basin indicates that there is a maximum temperature (after the summer solstice) and a minimum temperature (after the winter solstice). Increasing of temperature from winter to summer is somewhat slower than decreasing of temperature from summer to winter. On the other hand, temperature changes are less pronounced in winter and summer months and more pronounced in transitional seasons.

Positive mean temperature in January (0.6°C) is rare in Serbia because only a few synoptic stations have similar temperature in January: Niš -0,6°C (Ivanović et al, 2011). It is possible to find other synoptic stations in resources which have identical or higher temperature in January: Valjevo (0.6°C), Smederevska Palanka (0.7°C) (Meteorological yearbook RHMZS).

Also, the mean temperatures in July are highas well (21.9°C). Synoptic stations like Novi Sad-Rimski Šančevi, Sombor etc. show identical trend. Leskovac Basin (22.4°C), Niš Basin (22.5°C) (Ivanović et al, 2011) and especially Belgrade (23.0°C), where the influence of the urban heat island is dominant (Meteorological yearbook RHMZS), show higher temperatures. Based on these kind of temperatures from January and July it can be concluded that winters in Kragujevac are mild and that summers are warm. It should be expected that the surroundings is a few tenths of a degree cooler. Temperature amplitude is 21.0°C, which classifies this region as a territory with humid continental climate (amplitude is lower than 23°C) (Rakićević, 1980).

Mean maximum and mean minimum temperatures show the same flow as the mean monthly temperatures. When it comes to the mean maximum temperatures, the trend is similar in Leskovac Basin (17.6°C), Ćuprija (17,5°C), and Smederevska Palanka (17,4°C). On the other side, identical or similar mean minimum temperature was recorded in Niš Basin, Veliko Gradište (6,4°C), Negotin (6,7°C) (Ducić et al, 2005). Relief has a great influence on the flow of the mean monthly and extreme air temperatures because of the stations which have similar hypsometric range.

When it comes to the mean temperatures of the seasons, it can be noticed that the amplitude of the mean monthly temperatures is low and that autumn is warmer than spring. High temperatures in autumn, especially in September and October, have a great impact on vegetation period causing its prolongation. There are similar data in literature about Niš (Ivanović et al, 2011), Prizren (Ducić et al, 2005) and others. Based on the thermodromic coefficient we can come to a conclusion that Kragujevac and its surroundings have characteristics of the moderate-continental climate. Amplitude of the absolute air temperatures shows a great fluctuation, which is a general characteristic of the areas with the continental thermal regime.

Winters are long, but not too cold. Positive mean January temperature indicates the general nature of the winter in Kragujevac. However, periods with negative temperatures are certainly possible. Frosty days are characteristic for the winter part of the year and they can influence vegetation in April and during September. Cold days are not so rare, also. Summer is long and warm in the area of the Kragujevac Basin. During July and August all days have temperature over 25°C (summer days) and almost every other day is tropical.

With mean annual temperature of 11.6°C, Kragujevac and its surroundings are one of the warmest city areas in Serbia. The linear trend of the mean annual temperature change points to a deviation of 1.5°C from the average mean annual temperature, the situation when a climate of the city dominates modificatation of the air temperatures values.

The final goal of the thermal studies is a climate regionalization. The detailed climate map of Yugoslavia was made by A. Milutinović (1974) based on the Köppen climate classification (Šegota, 1988). According to said classification, Kragujevac and its surroundings belong to the Cfb climate “moderately warm, humid climate with a warm summer” (mean July temperature is about 20-22°C, and the mean January temperature is from 0°C to -3°C. According to the Köppen climate classification, T. Rakićević (1980) created even more detailed map of the Serbian climate regions (Ducić et al, 2005). Based on the classification it can be concluded that Cfbx climate is present in the Kragujevac Basin, which means that the temperature of the coldest month is above -3°C and under 18°C and the mean temperature of the warmest month is lower than 22°C. T. Rakićević (1980) established that Kragujevac and its surroundings belong to climate region of Šumadija, with four clearly pronounced seasons. The first half of autumn is especially pronounced as dry and warm.

Based on all the above said, we endeavored to give a small contribution to studies about the thermal regime of the Kragujevac Basin and urban area, with special emphasis on the last decay of the XX century and the beginning of the XXI century. However, it should be kept in mind that for a more detailed characterization of the thermal regime it is necessary to possesses series of longer observation. That way is possible to interpret changes and trends of the thermal regime more adequately.

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