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THE ASSESSMENT OF ARIDITY IN LESKOVAC BASIN, SERBIA (1981–2010)

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Abstract: In the paper, the aridity is defined on the basis of four climate indices: De Martonne's index of aridity, Lang's Rain Factor and Gračanin's Rain factor for the vegetation period and hydrothermal coefficient of Seljaninov. While the annual value of the drought index (I_{DM}) shows humid characteristics, the monthly values show the variability of the conditions. The summer months (July and August) are classified as semi-arid months, while the winter months (December–February) are extremely humid. The spatial distribution of the isoarids indicates that the northern part of the basin has the characteristics of a semiarid climate, while the southeastern parts are more humid. The analysis of mean annual values of the drought index indicates in semiarid conditions (1990 and 2000), but also the humid conditions (2005 and 2009). A positive linear trend indicates that there is a tendency towards humid conditions. The significance test confirms the existence of a statistically significant trend. During the vegetation period, semi-arid conditions are present (July–August). April is slightly humid, and October is moderately arid. The Lang's Rain Factor (KFg) characterizes basin climate as semiarid, while the Gračanin rain factor for the vegetation period (KFm) indicates a moisture deficit in the summer months. Hydrothermal coefficient Seljaninova (HTC) indicates a lack of moisture in July and August. Vegetation period is characterized as insufficiently humid. Irrigation is one of the most important measures for solving drought problems, since the yield varies from year to year.

Keywords: aridity, Leskovac basin, climatic indices, irrigation

Introduction

There are differences in the conceptual definition of aridity and drought. Aridity, defined as a constant lack of moisture, is based on average climatic conditions. It actually represents the specificity of the climate of a particular region (Dukić, 1980; Agnew & Anderson, 1992). In the literature, more attention is paid to arid

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and semi-arid areas of warmer climates. In them, the lack of moisture leads to major socioeconomic changes (due to the increased needs of the population for water). However, aridity also occurs in polar regions where precipitation exclusively occurs in the form of snow. The Antarctic and the Arctic are actually "ice deserts" with a small annual rainfall. Unlike aridity, drought is a temporary phenomenon in terms of lack of moisture (Maliva & Missimer, 2012). There are numerous quantitative indicators that show the appearance and character of aridity. They can be used individually or in combination with other climatic elements: precipitation, precipitation with medium air temperature, soil humidity, climate indices. De Marton (1925) uses "combined influence of air and precipitation temperature". In 1948, Thornthwaite used a humidity index for the distribution of dry areas on Earth (Thornthwaite, 1948). UNESCO (1979) defines the aridity index as the ratio between annual rainfall and potential evapotranspiration (UNESCO, 1979). Today, aridity indices are used in order to track and map regional climate change. The Intergovernmental Panel on Climate Change (IPCC) uses an annual rainfall only as a criterion for aridity. According to them, arid regions receive more than 250 mm precipitation, and semi-arid areas between 250–500 mm (IPCC, 2007). Causes of regional aridity can be classified into four categories (Agnew & Anderson, 1992):

– High air pressure — an atmospheric circulation known as the "Hadley cell", where the heated air rises above the equator and drops down descendingly into the subtropical regions. Thus, it brings dry and stable weather.
– Continental winds — the air currents move on the land and thus bypass water surfaces and do not bring humidity.
– The effect of "rain shadows" — air masses move along the upward side of the mountain, cool and condense. For this reason, the curved slopes become arid.
– Cold ocean currents — have a cooling effect on the air masses above the water surface; temperature inversion occurs, which prevents the ascending flow of air (lack of precipitation).

In the 21st century, the problem of climate change has been analyzed in numerous scientific studies. Aridness plays a special role in understanding the climatic conditions on Earth. Based on the estimates of the Intergovernmental Panel on Climate Change at the beginning of the 21st century, an average global temperature increases of 0.6 °C ± 0.2 °C were recorded (Ducić & Radovanović, 2005). On the other hand, by 2100, an increase in the global temperature is predicted to be 1.1–6.4 °C on average (Komac, Zorn, Gavrilov, & Marković, 2013). Over the past decades, the tendency of arid conditions and the higher incidence of extreme climatic events are generally present (Mishra & Singh, 2010; Trenberth, Fasullo, & Shepherd, 2015). In addition to increasing the average global temperature, an excellent indicator is the decrease of precipitation from 1900–2005. During the year, the precipitation amount decreased in Sahel, the Mediterranean, South Africa and parts of South Asia. The Balkan Peninsula and Central Europe are exposed to a moderate increase in the incidence of events. These tendencies have been more pronounced in recent decades, especially since the 1980s (Spinoni, Naumann, & Vogt, 2017).

The subject of the paper will be the aridity assessment based on the analysis of the variables (air temperature and precipitation), on the basis of which certain climatic indices are calculated. The problems of aridity and drought in the territory of Serbia are presented in numerous scientific works, among which we would like to highlight the following authors (Rakićević, 1988; Spasov, 2003; Ivanović, Bursać-Marti, & Đokić, 2007; Gocić & Trajković, 2013; Hrnjak et al., 2014; Urošev, Dolina, & Štrbac, 2016; Bačević et al., 2017, Radaković et al., 2018).

Study area

The geographical backbone of entire southeastern Serbia is the Moravian valley. It is located in the inner area of the Dinarides, the area of the Rhodope mass and on the western edge of the Carpathian and Balkan Mountains. Leskovac basin is a vast basin in the southern part of Serbia, in the composite valley of Južna Morava ("South Morava"). In the south, it starts with the Grdelic Gorge, and ends with the Pechenevce narrowing. In its north, there is the valley of Niš and on the south the valley of Vranje. It is located at an average altitude of 220 m. It is one of the largest basins of Serbia, with a width of 45 km, while it is 50 km long according to the meridian (Pavlović & Marković, 1995; Golubović, 2001). The river Južna Morava flows through the Leskovac basin. Apart from Južna Morava, the following larger rivers go through the Leskovac basin: the Jablanica, the Veternica, the Toplica, the Pusta reka, the Lužnica (Figure 1). Leskovac basin is located within the central part of the Balkan Peninsula, about 42° N. Therefore, it is largely isolated, i.e. the effects of the nearest seas are very weak. Because of this position, continentality is highly pronounced.

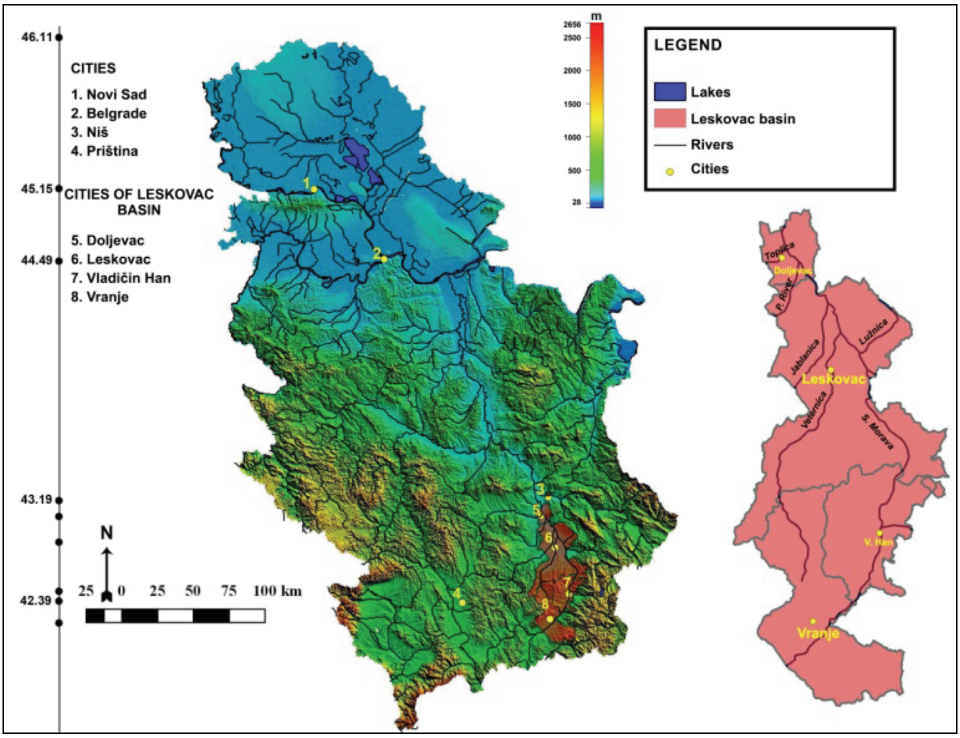

Figure 1. Geographical position of Leskovac basin within the Republic of Serbia

Methodology

In determining the aridity characteristics in the Leskovac basin, the data from the only higher-order synoptic station in the analyzed area, the Meteorological Station Leskovac, were used. The data were analyzed for a thirty-year period, from 1981 to 2010 (Meteorological annuals Republic Hydrometeorological Service of Serbia — climatological data). Based on the air temperature and rainfall values, the aridity indices are calculated. Special attention was paid to the following indexes:

– de Marton's drought index;
– Lang's rain factor;
– Gračanin's rain factor for the vegetation period;
– Seljanin's hydrothermal coefficient.

In 1926, E. De Martonne exhibited his famous annual *aridity index* I_{DM} :

$$I_{DM} = \frac{P}{T+10} \tag{1}$$

where *P* represent the mean annual precipitation and *T* represent mean annual air temperature (Croitoru, Piticar, Imbroane, & Burada, 2013). Monthly values of the De Martonne's aridity index can be calculated using the following equation:

$$Im_{DM} = \frac{12Pm}{Tm+10'} \tag{2}$$

where *Pm* is the mean monthly rainfall and Tm is the mean monthly air temperature (Hrnjak et al., 2014). The classification of monthly values of the drought index Im_{DM} is presented in the Table 1.

Table 1. Climate classification according to the De Martonne's aridity index

Im_{DM}	Climate classification
< 10	arid
11–24	semiarid
24–30	moderately arid
30–35	slightly humid
35–40	moderately humid
40–50	humid
50–60	very humid
60–187	extremely humid

Source: Monthly de Martonne Aridity Index – NTUA, 2017

In order to better understand the geospatial distribution of the De Martonne aridity index on the territory of the Leskovac basin, a modern GIS analysis was completed, supplemented by the method of interpolation. When only one measuring station of climatological data is available, the interpolation method is used for the purpose of better spatial distribution of climatic elements. In this paper, in order to present the spatial distribution schedule of the drought index, apart from the Meteorological Station Leskovac, the data of the stations within the radius of 100 km were used. Interpolation is based on the so-called Variable Grid Method (VGM). It is a relatively new and proven interpolation technique, where the error is reduced to a minimum (Sailesh, Dilip, Debasish, & Pal, 2011; Bauer & Rose, 2015). Geographic Information Systems (GIS) represents a powerful tool for numerical modeling and display of many geophysical data, including the climatological data. Geospatial data used for modeling and mapping are determined based on annual values of precipitation and air temperature. During the processing of data, the free software package QGIS and SAGA (Baltas, 2007; Franke, 1982) was used. In order to perform a statistical evaluation of the applied aridity index de Martonne, the Ordinary Least Squares regression (OLS) model was used, which minimizes the square deviations of all empirical points (i.e., quadratic residuals) from the regression line and has the following form (Wang, Dusnon, & Leng, 2016):

$$y_i = \alpha + \beta * x_i + \varepsilon_i \qquad \Rightarrow \qquad \varepsilon_i = y_i - \alpha - \beta * x_i \tag{3}$$

$$\widehat{y_i} = \widehat{\alpha} + \widehat{\beta} \cdot x_i + \widehat{\varepsilon_i} \tag{4}$$

$$\sum_{i=1}^{n} (Y_i - \widehat{Y_i})^2 = \sum_{i=1}^{n} (\widehat{\varepsilon_i})^2 = \min \tag{5}$$

The equation (3) function describes the relationship between *x* and *y*. The difference between the dependent variable y and the estimated systematic impact *x* on *y* is called residual (ε_i). In the case of OLS, this criterion is the sum of square residuals; alpha and beta are calculated if the sum of all square deviations (residuals) is minimal, as it is presented in the equations (4) and (5).

In addition to the regression analysis, a parametric significance test was used to estimate the existence or absence of a trend (Aranđelović, Mitrović, & Stojanović, 2011). In 1930, R. Fischer introduced the significance test into the literature. Using the significance test, the two hypotheses have been tested: zero hypothesis (H_0)*, which indicates the absence of a trend in the time series*; and an alternative hypothesis, H_a, where there is a statistically significant trend in the time series for the set level of significance (α). *P* value has the central role in the significance test. The value of p determines the level of reliability of the hypothesis. If the value of *p* is lower than the selected level of significance α (usually α = 0.05 or 5%), the (H_0) hypothesis should be rejected, and the hypothesis H_a should be accepted. In contrast, if *p* is higher than the level of significance α, then the (H_0) hypothesis is accepted (Fisher, 1925; Mudelsee, 2010; Hennemuth et al., 2013).

In 1915, R. Lang introduced the *rain factor* (*KFg*) in applied climatology, which is still regularly applied on climate aridity (Vujević, 1956; Oliver, 2005). It is obtained from the ratio of annual precipitation (*Pg*) and annual air temperature (*Tg*):

$$KF_g = \frac{P_g}{T_g} \quad (6)$$

In 1950, M. Gračanin introduces a *rain factor* (KF_m) for each month of the year. It represents the relationship between the monthly rainfall (P_m) and the mean monthly temperature for a given month (T_m):

$$KF_m = \frac{P_m}{T_m} \quad (7)$$

For the needs of the paper we will perform the analysis of the rain factor during the vegetation period. Gračanin performed a gradation of the value of the monthly rain factor (Šegota & Filipčić, 1996), Table 2.

Table 2. Classification of climates according to the monthly rain factor according to Gračanin

KFm	Climate classification
< 3.3	arid
3.3–5	semiarid
5–6.6	semihumid
6.6–13.3	humid
> 13.3	perhumid

Source: Šegota, Filipčić,1996

Hydrothermal coefficient (HTC) was developed by Seljaninov (1958). It is about the so-called conditional balance of moisture, which characterizes the humidity of a certain territory. It represents the ratio of precipitation and the sum of active temperatures during vegetation or shorter periods:

$$HTC = \frac{P}{\sum_{t>10} \frac{T}{10}} \quad (8)$$

HTC's limit values are customized for the territory of Serbia (Otorepec, 1991, Table 3).

Table 3. Classification of climates according to Seljanin's hydrothermal coefficient

HTC	Climate classification
< 0.7	very arid
0.7–1.0	arid
1.0–1.3	insufficiently humid
> 1.3	humid

Source: Otorepec, (1991)

Results and Discussion

Aridity index

Although the annual value of the De Martonne aridity index is more commonly used in climatology, monthly values provide a better timing distribution of aridity index (Table 4).

Table 4. Monthly values of the De Martonne aridity index (Im_{DM}) in the Leskovac basin (1981–2010)

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
50.6	46.9	33.6	33.9	25.4	25.9	16.8	18.2	23.5	28.9	47.9	58.1	29.6

Source: Meteorological Yearbook of Republic Hydrometeorological Service of Serbia - climatological data

The data from the previous table indicate that only July is classified into partially dry months, which corresponds to the conditions of steppe vegetation. Only August shows aridity limit values, while other months, despite high temperatures, have higher aridity index values. The autumn and winter months (November–February) show highly humid conditions. Spring months (March–April) show lower humidity level. The annual value of Im_{DM} is on the boundary of moderately arid and slightly humid climate. The spatial distribution of the aridity index is shown in the Figure 2. The lowest values of the aridity index are determined by the isoarid 20.1–21 in the north of the Leskovac basin. The highest values (> 29.1) are registered in one area. The area is located in the southeastern part of the basin. This is related to the higher annual sum of precipitation due to terrain orography (Kukavica, Čemernik, Babička Gora and Suva planina). We can see that similar orographic conditions, which are in correlation with higher humidity, occur in the southern part of Kosovo and Metohija. The more pronounced dissection of the relief (Prokletije, Paštrik and Koritnik) is the cause of the higher value of the aridity index (> 37.5) (Bačević et al., 2017). Isoarid 28.1–29 marks an area with a slightly higher index value, in the central part of the basin. Therefore, we conclude that the northern part of the basin has the characteristics of a semiarid climate, while the southeastern parts have more humid climatic influences. It is clear that Leskovac basin is on the boundary of semi-arid and humid climate. For comparison, the northern parts of Vojvodina have characteristics of the semi-humid climate, while the southern regions have a humid climate (Hrnjak et al., 2014).

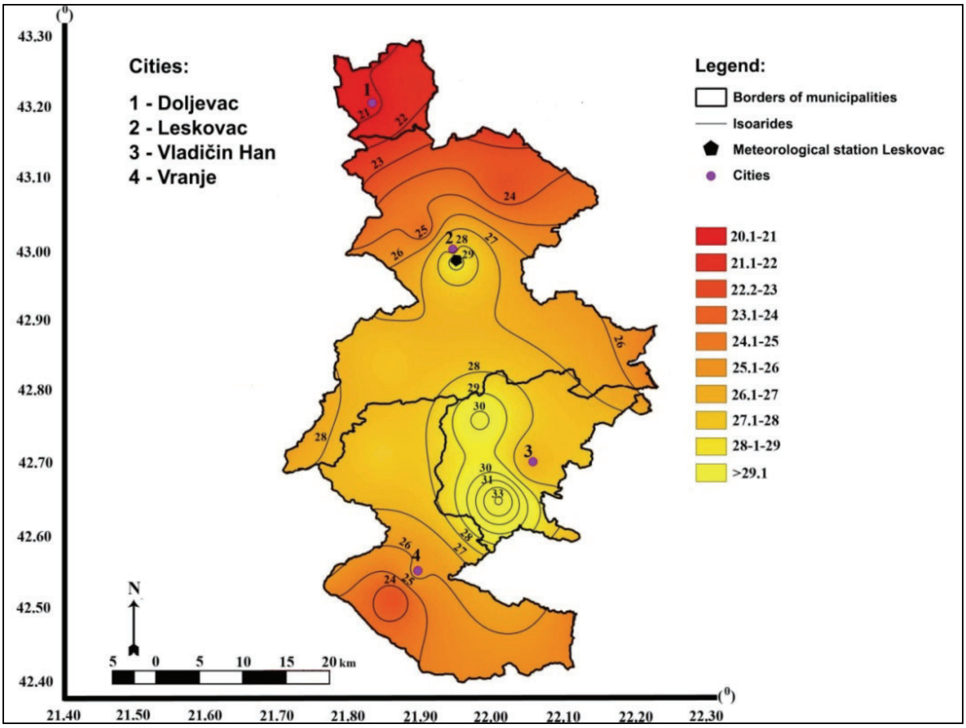

Figure 2. Spatial distribution of the De Martonne aridity index in the Leskovac basin (1981–2010)

The analysis of the aridity index is not complete without a more detailed analysis of the average annual values of the aridity index (Figure 3). There is a pronounced variability of its value. For example, the minimum value of the annual index was recorded in 2000 (19.1) and 1990 (19.6). The values correspond to the conditions of the semiarid climate. On the other hand, the maximum annual index in 2009 was 37.6, in 1998 it was 37.4 and in 2005 it was 37.1. These values indicate extremely humid conditions in Leskovac basin. These details indicate the exceptional diversity of climatic conditions. The equation of the linear trend has the following form:

$$y = 0.2078x + 26.473 \quad (9)$$

The linear trend in the thirty-year-long series determined by the least squares method shows that humidity increases by 0.2 per year (or 2 per decade). The existence of a linear trend is confirmed based on the significance test. The calculated value of p (0.04) is lower than the selected significance level (α = 0.05), which means that the hypothesis H_o cannot be accepted. Therefore, the value of p points to the existence of a statistically significant trend.

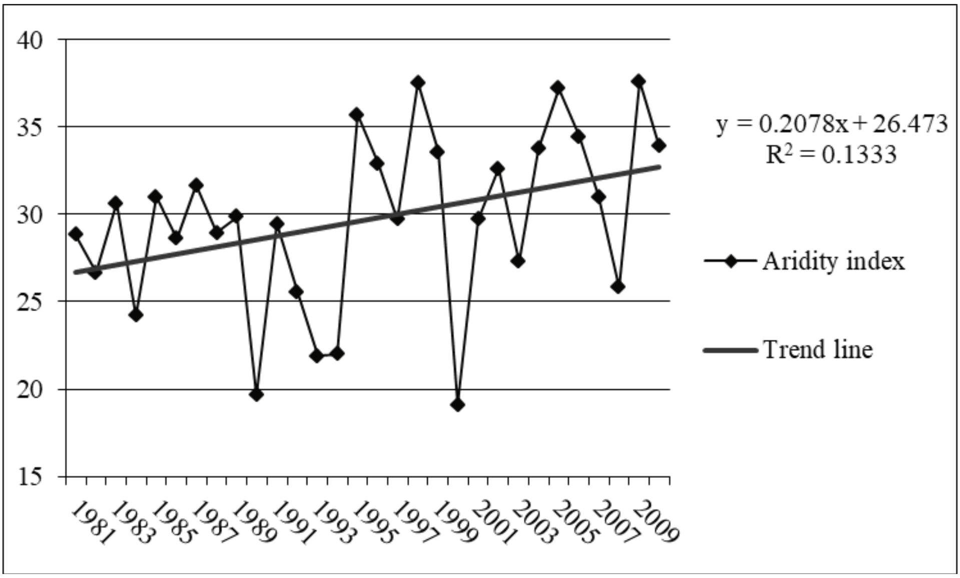

Figure 3. Changes in the average annual values of the drought index I_{DM} and the aridity trend line in Leskovac (1981–2010)

The average annual values of the de Martonne drought index indicate the distribution of moist or dry years. A better idea of the aridity character is obtained by analyzing the drought index during the vegetation period (Figure 4). The beginning of the vegetation period has a characteristic of insignificant humidity (April). May and June are moderately arid. Summer months (July–August), as well as September, are semi-arid. Category of arid is not represented. The end of the vegetation period is characterized as moderately arid (October).

Lang's Rain Factor

Based on the ratio of the mean annual precipitation and air temperature, for the Leskovac basin, the value of the rain factor was 56.3. According to the Lang's gradation, the climate of the basin is characterized as semi-arid, but at the upper limit of semi-aridity. The data from Meteorological Station (MS) Leskovac show that according to the rain factor, Leskovac basin belongs to the drier areas of Serbia. Thus, similar dryness occurs in Meteorological Station (MS) Novi Sad (56.9), MS Kragujevac (56.3), while lower dryness coefficient occurs in MS Vranje (52.2) and MS Niš, with rain factor 47.0 (Rakićević, 1988).

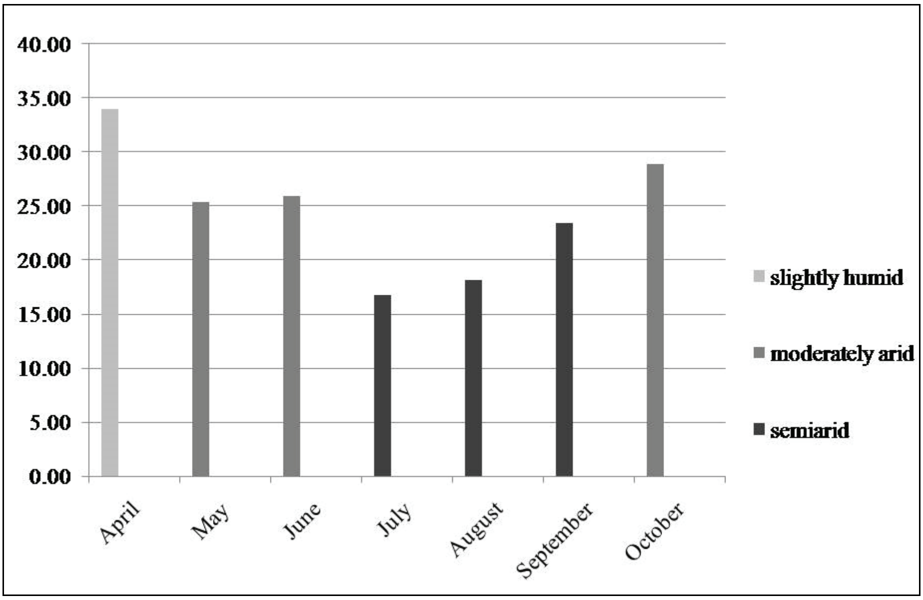

Figure 4. Monthly distribution of the drought index Im_{DM} for the vegetation period in Leskovac (1981–2010)

Gračanin's rain factor

Using monthly rainfall values and mean monthly air temperatures during the vegetation period, the monthly rain factor was calculated (Table 5).

Table 5. Values of rainfall factor *KFm* and humidity mark during the vegetation period in Leskovac basin (1981-2010)

Months	April	May	June	July	August	September	October	Vegetation period
KFm	5.3	3.4	3.3	2.0	2.2	3.2	4.6	3.2
Humidity mark	semi-humid	semi-arid	semi-arid	arid	arid	arid	semi-arid	arid

Source: Meteorological Yearbook of Republic Hydrometeorological Service of Serbia

The values of the Gračanin rainfall factor during the vegetation period indicate that July and August are arid, so the lack of moisture is a limiting factor when it comes to the development of plants. The exception is June (semiarid), but in general, during the summer months, there is not enough moisture. April is semi-humid, while May has the mark of semi-aridity, which is unfavorable from the phenological aspect. September is arid, while the end of the vegetation period is semiarid, which also does not represent a favorable circumstance for the vegetation. All in all, the vegetation period is assessed as arid.

Seljanin's hydrothermal coefficient

At the beginning of the vegetation period, the humidity is favorable with a HTC value of 1.77 (Table 6). This moisture especially favors the plant world. May is insufficiently humid (1.1). Humidity conditions vary in the summer half of the year (from insufficiently humid to arid). The minimum humidity in the vegetation period is observed in July (0.66 — very arid). The lack of moisture in July and August is a limiting factor for cultivating plants. The autumn months (September–October) are not sufficiently humid. In terms of humidity, they show similar values as the spring months (April–May). On the whole, the vegetation period is at the lower limit of humidity.

Table 6. Values of the Seljanin's hydrothermal coefficient HTC and the humidity mark during the vegetation period in Leskovac (1981–2010)

Months	April	May	June	July	August	September	October	Vegetation period
HTC	1.77	1.1	1.1	0.66	0.71	1.1	1.47	1.04
Humidity mark	humid	insuf. humid	insuf. humid	very arid	arid	insuf. humid	insuf. humid	insuf. humid

Source: Meteorological Yearbook RHMZ - climatological data

Conclusion

Climate index analysis was used to identify the appearance of aridity. Monthly values of the de Martonne drought index indicate a partial aridity in July and August, with drought limit values. The period from November to February is extremely humid, while March–April is slightly less humid. The mean annual value of the drought index (29.6) is somewhere between moderately arid and slightly humid climate. The geospatial arrangement of the isoarids is determined using the GIS tools and the interpolation method, as this results in a higher accuracy of the results. The isoarids indicate the semiaridity of the northern part of the basin, while the central and southeastern parts are humid. Similar conditions of humidity, in correlation with terrain orography, we meet in the southern part of Kosovo and Metohija. For comparison, as much as 75% of the territory of Vojvodina is characterized by humid climate (Hrnjak et al., 2014), while the Leskovac basin is dry (on the border between semi-humid and humid climate). The time distribution of the mean annual values of drought indexes indicates the variability of its value. Thus, 1990 and 2000 correspond to the conditions of the semiarid climate, while 1998, 2005 and 2009 correspond to the conditions of the humid climate. The method of least squares linear regression indicates that there is a tendency in the Leskovac basin to reduce aridity conditions. The existence of a statistically significant trend in the mean annual values of the drought index is confirmed by the significance test ($p < \alpha$).

Although the vegetation period is characterized by the variability of the monthly values of the drought index, the aridity is not represented in the right way. The value of Lang's rain factor (56.3) is also indicative of the semi-aridity of the Leskovac basin climate. In the phenological sense, Gračanin's rain factor is particularly significant. The lowest values of the monthly rainfall during the vegetation period were recorded in July, August and September, which are arid, according to the moisture mark, while the values characterized by semiaridity were recorded in June and May. Seljanin's hydrothermal coefficient indicates that only the beginning of the vegetation period is humid (April). In terms of aridity, July and August are particularly critical. The rest of the vegetation period is insufficiently humid. The results presented indicate the occurrence of aridity in the summer half of the year, which is a limiting factor in agriculture. Irrigation is an effective measure in the fight against aridity. Using irrigation systems, in wet years, the unequal distribution of precipitation would be corrected, and in the dry conditions, the humidity deficit would be eliminated. Two important factors that make today's agricultural production unsustainable: a) obsolescence, neglect or absence of irrigation systems; b) the absence of a methodology for forecasting natural disasters, prevention and reduction of damage incurred (Armenski et al., 2014). For this reason, the presented results form the basis of further research of aridity in Leskovac basin. In this regard, the analysis of long series of observations of climatic elements would provide an adequate idea of aridity. Aridity and drought must also be addressed through the preparation of planning documents in order to take adequate measures and propose appropriate solutions.

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