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THE SPECIFICITIES OF THE CLIMATE OF DANILOVGRAD (MONTENEGRO)

Abstract: Danilovgrad and the Bjelopavlića Plain belong to the submediterranean zone of the Mediterranean climate region. The aim of this paper was to determine some specific characteristics of the Danilovgrad climate, such as the degree of continentality, aridity and bioclimatic characteristics. Data used in the research cover the period 1955–2011. The results of the study showed the dominance of the continental effect on temperature, while oceanicity was less pronounced. In hygric terms, during most of the year the climate of Danilovgrad is characterized as low humid to perhumid. Moreover, in the period October–March it is very humid, which points to the domination of oceanic influences. During the three summer months, it is dry to very dry. Based on the average monthly values of the equivalent temperature – an indicator of physiological (subjective) feeling of heat, the winter months in Danilovgrad are not assessed as very cold. It is cold in January, and in February and December it is cool. It is fresh in March and November, comfortable in April and October, and warm in May and September. In Danilovgrad, in summer it is overheated and a little muggy. All considered indicators point to quite pronounced oscillations during the year, especially in terms of humidity. Comparing the obtained results with Podgorica, it can be concluded that the climate of Danilovgrad is more continental, a bit colder and wetter.

Key words: climate, continentality, aridity, bioclimate, Danilovgrad

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Introduction

There are many reasons why we decided to consider the specificities of the Danilovgrad climate. First, in all known climate classifications of Montenegro, a general description of individual regions and sites is mainly based on the analysis of average monthly air temperatures and amount of precipitation. In general, Danilovgrad can be said to have a mildly modified Mediterranean climate, which means that the summers are warm and fairly dry, and the winters are mild and rainy. In the period 1955–2011, in Danilovgrad, the average annual temperature was 14.6°C, and the annual amount of precipitation was 2,216 mm. Tab. 1 contains the values of the average air temperature and the amount of precipitation in Danilovgrad.

Tab. 1. The average seasonal air temperature and the amount of precipitation in Danilovgrad in the period 1951-2011

Season	Average air temperature (°C)	Amount of precipitation (mm)
Winter	5.6	787.2
Spring	13.8	477.4
Summer	24.0	213.3
Autumn	14.8	731.8

Therefore, apart from the general characteristics, the specificities of the climate of Danilovgrad considered in our study are not known. Secondly, Danilovgrad is the central settlement of the Bjelopavlića Plain. The Danilovgrad climatological station was the only one in that area. In the Bjelopavlića Plain, the basic occupation of the population is agriculture, and this is another reason for the research of the specificities of the Danilovgrad climate. Thirdly, only Danilovgrad and Podgorica have recorded an increase in the number of inhabitants among continental cities in Montenegro (https://www.monstat.org/cg/). It is primarily a result of migration from the north of the country. Finally, the meteorological station in Danilovgrad was canceled at the beginning of 2012. Having the above in mind, the idea was to describe the climate of the city by analyzing the combined climatic elements. The basic goals of the research are, therefore, a more complex presentation and a qualitative characterization of the Danilovgrad climate.

It is necessary to emphasize that Danilovgrad and a significant part of Montenegro have characteristics of the Mediterranean climate. This is also confirmed by the criteria set by V. Köppen (Burić et al., 2013, 2014). Köppen's classification is hydrothermal (an analysis of air temperature and precipitation) and it gives a realistic image of the climate of a certain site or territory, but it is often necessary to determine some specificities of climate. The specificities of the climate are determined by the analysis of combined climatic elements, calculated from two or more basic climatic elements, which had better characterize the climate of a site. In this paper, the specific characteristics of the climate, such as the degree of continentality, aridity and bioclimatic characteristics were analyzed on the example of the city of Danilovgrad.

Vujević (1956; 1961) wrote about the specificities of the climate of certain parts of the Balkan Peninsula. In other works, the influence of weather and climate on human body is also considered (Pecelj, 1996; Burić, 2007; Pecelj et al., 2007; Lukić & Đorđević, 2009; Malinović-Milićević, 2013; Basarin et al., 2014; Pecelj et al., 2017; Basarin et al., 2017).

The analysis of climatic indexes of urban places was a subject of research by Matzarakis & Endler (2010), Matzarakis & Nastos (2011), Pecelj, (2013) and Pecelj et al. (2013). Some specific features of the climate of spas were considered in the papers of Pecelj (1996), Maćejka (2003) and Stojićević et al. (2016).

Materials and methods

The study refers to the area of Danilovgrad, the central and largest city settlement in the Bjelopavlića Plain in Montenegro. Danilovgrad is situated in the spacious valley bottom of the Zeta River (the largest tributary of the Morača River), i.e. on its coast. The area of Danilovgrad municipality is 501 km², and there are approximately 17,000 inhabitants in the area. The city settlement is in the plain, mostly at 50–60 m a.s.l. (Fig. 1). The valley sides of the Zeta River make the mountain Garač (right side), up to 1,436 m a.s.l. and Prekornica (left side), with the highest peak of 1,927 m a.s.l. The geographic coordinates of the climatological station are 42°33' N, 19°06' E and 53 m a.s.l.

Fig. 1. Position of Danilovgrad in Montenegro

The specificities of the Danilovgrad climate were considered on the basis of the data for the period 1955 to 2011. The data are from climatological station and they are mostly completed, and the testing and the verification of the data has shown that the measurements are reliable (CLIDATA database of the Institute of Hydrometeorology and Seismology of Montenegro was used).

In methodological terms, climate specificities of Danilovgrad have been determined on the basis of appropriate forms. Thus, the continentality of climate is calculated on the basis of the Gorczynski (Gorczyński, 1918), Conrad (Conrad, 1946) and Kerner (Kerner, 1905) formulas, and the aridity by Gracanin rain factor (Gračanin, 1950) and de Marton (De Martonne, 1926) and Lobova indexes (Lobova et al., 1977). The bioclimatic characteristics of this city were determined using the Beckold formula (Vujević, 1956) and the Krüger anthropoclimate classification (Đukanović, 2000). The above methods have been used in this research because they have been verified, i.e. applicable to the region of the Balkans.

The thermal degree of a continentality of Gorczynski (K) takes into account the latitude (φ) and the amplitude of the annual air temperature (A). It is expressed in percentages and calculated according to formula:

$$K = 1.7(A - 12\sin\varphi)/\sin\varphi$$

According to Conrad, thermic continentality is calculated from the formula (the labels are the same as in the previous formula):

$$K = \frac{1.7 \cdot A}{\sin \cdot (\varphi + 10)} - 14$$

Kerner introduced the thermodrome quotient (K), obtained by the formula:

$$K = (T_X - T_{IV})/A \cdot 100\%$$

T_X – average October temperature (for Danilovgrad 14.7°C);

T_{IV} – average April temperature (for Danilovgrad 13.5°C);

A – average annual temperature amplitude.

October and April are chosen because their average temperatures are the closest to the annual value (Danilovgrad = 14.6°C).

Gračanin rain factor (KF_m) is calculated as the ratio between monthly average amounts of precipitation (R_{ma}) and air temperature (t_{ma}):

$$KF_m = R_{ma}/ t_{ma}$$

De Marton drought index (I) was used to estimate the aridity, and calculated as the ratio of annual precipitation (R_{ya}) and mean annual temperature (t_{ya}), according to the formula:

$$I_y = R_{ya}/(t_{ya} + 10^\circ)$$

For the monthly values, the formula is slightly changed:

$$I_m = 12R_{ma}/(t_{ma} + 10^\circ).$$

Lobova index (V_a) is used to estimate the aridity, on the basis of formula:

$$V_a = R_{ya} /(6.12\ \Sigma t_a A\text{-}O + 30.6)$$

R_{ya} – average annual precipitation; $\Sigma t_a A$-O – sum of average monthly temperature from April to October.

The bioclimatic characteristics of Danilovgrad are determined on the basis of the annual change of the air temperature (t) and the water vapor pressure (e). The equivalent temperature in Danilovgrad were calculated using the Beckold formula ($E_t = t + 2e$). Krüger anthropoclimate classification was used for the categorization, which included three weather types and nine physiological feelings of heat (Đukanović, 2000).

Results and discussion

Continentality and aridity of the climate of Danilovgrad

By applying the **Gorczynski** formula for Danilovgrad (φ = 42°33'; A=20.4°C), the thermal degree of climate continentality K = 30.8%. A similar value was obtained using the **Conrad** formula, K = 29.7%.

According to **Kerner**, continentality of climate in Danilovgrad is **K = 6.0%** and the limit of oceanicity is 15%. If K < 15 climate has continental gradations, and if K > 15 it is maritime, while negative values indicate a distinct continentality.

Therefore, previously considered indicators clearly show that the effects of oceanicity and continentality in the thermal sense are intertwined in this area. However, based on the thermodrome coefficient, the Danilovgrad climate has moderate continental characteristics. The thermal coefficient in Podgorica is higher, close to 10% (Burić et al., 2007), which indicates that this city has weaker continental characteristics. That is logical because it is closer and more open to the Adriatic Sea (Mediterranean) than Danilovgrad.

The results obtained for the rain factor are given in Tab. 2, and based on the gradation[2] given by Gračanin, appropriate conclusions have been drawn.

Tab. 2. Monthly rain factor in Danilovgrad

Rain Factor	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	51.4	36.1	20.1	13.1	5.9	3.8	2.0	3.2	7.9	16.3	34.4	54.0

The arid months are July and August, and June is semi-arid. May has semihumid characteristics, and April and September are humid. Cold half of the year, from October to March, has characteristics of high humidity, that is, these months are perhumid. In other words, the summer in Danilovgrad is characterized as dry to very dry and cooler part of the year, especially winter, as very moist (perhumid).

Tab. 3 shows the values of de Marton drought index. Based on the categorization[3] given by same author the conclusions were drawn for Danilovgrad.

[2] According to gradation by Gracanin, climate is: arid ($KF_m < 3.3$), semi-arid ($KF_m = 3.3 – 5$), semi-humid ($KF_m = 5 – 6.6$), humid ($KF_m = 6.6 – 13.3$) and perhumid ($KF_m > 13.3$).

[3] Gradation by de Marton: if I > 5, climate is desert (areic areas), I = 5 – 10, climate is semi-desert (border endorheic areas), I = 10 – 20, steppe vegetation (endorheic or egzorheic drainage), I = 20 – 30, forest-steppe vegetation (egzorheic drainage), I = 20 – 40 forest vegetation (egzorheic drainage), I > 40, abundant egzorheic drainage.

Tab. 3. Drought index for Danilovgrad

Drought index	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	197.3	166.5	117.9	90.5	45.6	31.3	16.9	27.6	63.0	116.5	203.2	241.1

Only July would be partly arid (steppe vegetation), while August has the characteristics of forest-steppe climate and June has the characteristics of almost forest vegetation. All other months have high values of the drought index (> 40), especially the period October–March (over 100), and according to the gradation, this means that there is an abundant drainage of precipitation. The annual value of the drought index (89.9) shows high humidity, which allows constant and abundant drainage.

According to the Lobova formula, Aridity index in Danilovgrad is V_a = 2.5, which means that the climate of the city in the period April–October is semi-humid. Semi-humid climate has the values of index between 2.01 and 3.0. According to this indicator, the climate of Podgorica (Burić et al., 2007) is poorly arid in the period April–October (V_a = 1.8). This is supported by the fact that in Danilovgrad all the months have higher precipitation than in Podgorica, and the difference is close to 550 mm per year.

Bioclimatic characteristics of Danilovgrad

The temperature and the wind have the greatest influence on the feeling of heat and cold of a human. In summer, high air temperature and high air humidity cause a feeling of muggy, so the impression is that it is warmer than it actually is. The wind accelerates the removal of heat from the surface of the body, and in winter, it increases the sense of cold (Burić, 2007). Several bioclimatic parameters are used in bioclimatic research (Vujević, 1956).

Bioclimatic characteristics of Danilovgrad have been determined based on average monthly values of equivalent temperature[4]. Observed as a whole (based on the annual values of air temperature and water vapor pressure) it is pleasant in Danilovgrad, with a mean annual equivalent temperature of 34.9°C. The results indicate the following (Tab. 4):

- Cold (5°C < E_t < 22°C) is during winter, January (E_t = 16.0°C) is classified in class cold, it is very cool in December (E_t =18.9°C), while February is on the boundary between cold and very cool (E_t = 18.0°C).
- Pleasant weather type (22°C < E_t < 50°C) is characteristic for transitional seasons. It is fresh in March (E_t = 23.5°C) and November (E_t = 26.5°C), comfortable in April (E_t = 31.2°C) and October (E_t = 36.4°C), and warm in May (E_t = 42.1°C) and September (E_t = 46.8°C).
- Overheated weather type (50°C < E_t < 70°C) is characteristic of all three summer months with class a little muggy (in June Et = 50.5°C, in July 54.7°C and in August 54.0°C).

[4] Equivalent temperature is the theoretical size, and it is defined as the temperature of dry air that it would have if all vapor condensed in the humid air, and then the released heat transferred to the dry air.

Tab. 4. Weather types and physiological feeling of warmth according to equivalent formula (E_t) in Danilovgrad

Weather Types	Classification (by E. Krüger)	Physiolog. feeling of warmth - classes (by E. Krüger)	Monthly values of equivalent temperature in Danilovgrad
COLD	E_t < 5°C	Very cold	no
	E_t 5 – 18°C	Cold	January (16.0°C)
	E_t 18 – 22°C	Cool	Feb. (18.0°C), Dec. (18.9°C)
PLEASANT	E_t 22 – 30°C	Fresh	March (23.5°C), Nov. (26.5°C)
	E_t 30 – 40°C	Comfortable	April (31.2°C), Oct. (36.4°C)
	E_t 40 – 50°C	Warm	May (42.1°C), Sept. (46.8°C)
OVERHEATED	E_t 50 – 58°C	A little muggy	June (50.5°C), July (54.7°C), August (54.0°C)
	E_t 58 – 70°C	Muggy	no
	E_t > 70°C	Very muggy	no

This indicator also shows that Danilovgrad and Podgorica have similar climate characteristics. However, equivalent temperature in Danilovgrad is somewhat lower, which indicates that Podgorica (Burić et al., 2007) is generally warmer throughout the year. In comparison to Danilovgrad, Valjevo (Serbia) is a more continental and bioclimaticly colder place. Namely, in Valjevo summers are warm, but not overheated as in Danilovgrad. In Valjevo, it is cold during four months, December–March (Đukanović, 2000), and in Danilovgrad only in January. From the aspect of the physiological feeling of heat, April and October are fresh in Valjevo, and in Danilovgrad they are pleasant.

Conclusion

Montenegro is scarce in flatland, and the continental part of the country records depopulation. Podgorica and Danilovgrad are the only two municipalities in the continental part of Montenegro that recorded an increase in the number of inhabitants. From a climatic point of view, Danilovgrad is a place that is perfect for life, and the population in the area deals mainly with agriculture. Based on previous facts (settling and agricultural activities), our goal was to point out some specific characteristics of the Danilovgrad climate, through the analysis of thermal continentality, aridity and bioclimatic characteristics. This is the basic novelty of the research, since there is almost no research for the area of Montenegro dealing with more detailed indicators of the specificity of climate of particular cities or regions. We believe that research will be relevant for the local community in terms of better understanding of the natural environment. The obtained results can be applied in agriculture, water management and energetics, tourism and other activities of importance for the future development of Danilovgrad and Montenegro. In addition, the obtained results will be useful to science, professional and general education of the population, because the topic is increasingly involved with today's civilization.

The analysis of thermal parameters showed that Danilovgrad is a continental city, while the maritime influence of the Adriatic Sea (Mediterranean) is less pronounced. In hygric terms, during most of the year the climate of Danilovgrade is characterized as poorly humid to very humid. It is especially humid (perhumid) in the period from October to March. Only summer months have characteristics of aridity, which suggests that Danilovgrad has a typical Mediterranean pluviometric regime.

According to bioclimatic indicators, there are no very cold months. It is cold in January, and in February and December, it is very cool. It is fresh in March and November, comfortable in April and October, and warm in May and September. The summer is overheated and a little muggy.

All indicators point that Danilovgrad has similar thermal, hygric and bioclimatic characteristics as Podgorica (Burić et al., 2007). It was expected because the distance between these two cities is about 20 km. However, there are obvious differences – Danilovgrad is more continental, a bit colder and wetter than Podgorica.

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Zavod za hidrometeorologiju i seizmologiju Crne Gore, baza podataka 1955–2011.

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СПЕЦИФИЧНОСТИ КЛИМЕ ДАНИЛОВГРАДА (ЦРНА ГОРА)

Резиме: Даниловград је централно и највеће насеље на подручју Бјелопавлићке равнице у Црној Гори. Са климатског аспекта, подручје Бјелопавлићке равнице је погодно за живот и развој пољопривреде. Међутим, у до сада познатим класификацијама климе за Црну Гору, дат је уопштени опис појединих регија и места, углавном на основу анализе средњих месечних температура ваздуха и количине падавина. За Даниловград се може рећи да има благо модификовну медитеранску климу, а то значи да су лета топла и прилично сушна, а зиме благе и кишовите. Према Кепеновој класификацији, климатска формула Даниловграда је Csa, просечна годишња температура је 14,6°C, а годишња сума падавина 2.216 mm. Циљ нам је био да климу овог места што боље и подробније опишемо, кроз анализу термичке континенталности, аридности и биоклиматске карактеристике. Анализом комбинованих климатских елемената, дат је комплекснији приказ и квалитетнија карактеризација климе Даниловграда. Сматрамо да ће истраживање имати значаја за локалну заједницу у смислу бољег разумевања природног окружења и да се добијени резултати могу применити у пољопривреди, водопривреди и енергетици, туризму и другим делатностима од важности за будући развој Даниловграда и Црне Горе. Такође, резултати добијени у овом раду биће корисни науци, струци и општем образовању становништва, јер се ради о тематици која све више партиципира код данашњег човека.

За разматрање специфичности климе Даниловграда, коришћени су подаци за инструментални период 1955-2011. Резултати истраживања су показали доминацију континенталног утицаја на температуру, док је маритимност слабије изражена. У хигричком смислу, током већег дела године клима Даниловграда се карактерише као слабо хумидна до перхумидна. Штавише, у периоду октобар - март је веома влажно, што говори о доминацији маритимних уплива. Сушно до веома сушно је током три летња месеца. Према биоклиматским показатељима, ни један месец се не карактерише као веома хладан. На основу средњих месечних вредности еквивалентне температуре, која је коришћена као показатељ физиолошког (субјективног) осећаја топлоте, током јануара је хладно, а у фебруару и децембру веома прохладно. Свеже је у марту и новембру, угодно у априлу и октобру, а топло у мају и септембру. У Даниловграду је лети прегрејано и мало запарно. Сви разматрани показатељи указују на прилично изражене осцилације током године, нарочито у погледу влажности. Добијени резултати указују да Даниловград има сличне термичке, хигричке и биоклиматске карактеристике као Подгорица (Бурић et al., 2007), јер је растојање између ова два града око 20 km. Ипак, Даниловград је више континенталнији, мало хладнији и влажнији од Подгорице.