

# **Ecoclimatic characteristics of the south-western slope of the Pirin Mountains (Bulgaria)**

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## **Abstract**

The paper characterizes thermal and humidity conditions within one of the insufficiently investigated parts of Bulgaria from the climate point of view, namely the south-western slope of the Pirin Mountains. The initial data for the study (monthly temperatures and precipitation amounts) were obtained from our own meteorological monitoring station for the period 2013-2021, organized by the Department of Climatology, Hydrology and Geomorphology, Sofia University, Bulgaria. By the calculation of Mayr tetratherm (MT), monthly De Martonne aridity index (Im) and Compensated Summer Ombrothermic index (CSOI) the predominance of humid conditions in the studied area is established. There is a large inter-annual variability of the De Martonne aridity index and the Compensated Summer Ombrothermic index, which are more influenced by precipitation than air temperature in the middle part of the mountains. On the other hand, in combination with low precipitation amounts, high temperatures in recent years have contributed to the manifestation of arid features of the climate. The results of the study supplement the insufficient information about the bioclimatic characteristics of the Pirin Mountains and clarify the peculiarities of the climate in these mountains, which have two clearly distinguishable macroslopes with west-southwest and east-northeast exposure.

**Keywords:** *Mayr tetratherm index, De Martonne index, Compensated Summer Ombrothermic index, Pirin Mountains*

## **Rezumat. Caracteristicile ecoclimatice ale versantului sud-vestic al Munților Pirin (Bulgaria)**

Lucrarea caracterizează condițiile termice și de umiditate în unul din arealele insuficient investigate din punct de vedere climatic ale Bulgariei și anume versantul sud-vestic al Munților Pirin. Datele inițiale pentru studiu (temperaturile lunare și cantitățile de precipitații) au fost obținute de la stația proprie de monitorizare meteorologică pentru perioada 2013-2021, organizată de Departamentul de Climatologie, Hidrologie și Geomorfologie, Universitatea din Sofia, Bulgaria. Prin calculul tetratermei Mayr (MT), indicelui de ariditate lunar De Martonne (Im) și indicelui ombrotermic compensat de vară (CSOI) se stabilește predominanța condițiilor de umiditate în zona studiată. Există o variabilitate interanuală mare a indicelui de ariditate De Martonne și a indicelui ombrotermic compensat de vară, care sunt mai influențați de cantitatea de precipitații decât de temperatura aerului în zona mediană munților. Pe de altă parte, în combinație cu cantități mici de precipitații, temperaturile ridicate din ultimii ani au contribuit la manifestarea caracteristicilor aride ale climei. Rezultatele studiului completează informațiile insuficiente despre caracteristicile bioclimatice ale Munților Pirin și clarifică particularitățile climei montane din zonă, unde se evidențiază două macropante cu expunere vest-sud-vest și est-nord-est.

**Cuvinte-cheie:** *Tetraterma Mayr, indicele De Martonne, indicele ombrotermic compensat de vară, Munții Pirin*

## **Introduction**

Recent climate trends show increase of air temperatures combined with decrease of precipitation in South Europe including Bulgaria. On the background of these tendencies, the feature of contemporary climate is the increase of the frequency of extreme events: heat waves, drought, heavy rainfall, etc. (IPCC, 2012, 2014, 2021). Climatic elements and changes in their regime, as well as the occurrence of extreme climatic events have a significant impact on the natural environment through changes in temperature and humidity conditions (Benito-Garzon et al., 2008; Kramer et al., 2010; Scharnweber et al., 2011; Vlăduț et al., 2017; Gavrilov et al., 2019; Nikolova & Yanakiev, 2020). There are many publications which analysed the relationship climate – vegetation. The direct and indirect effects of climate on vegetation can be both positive (related

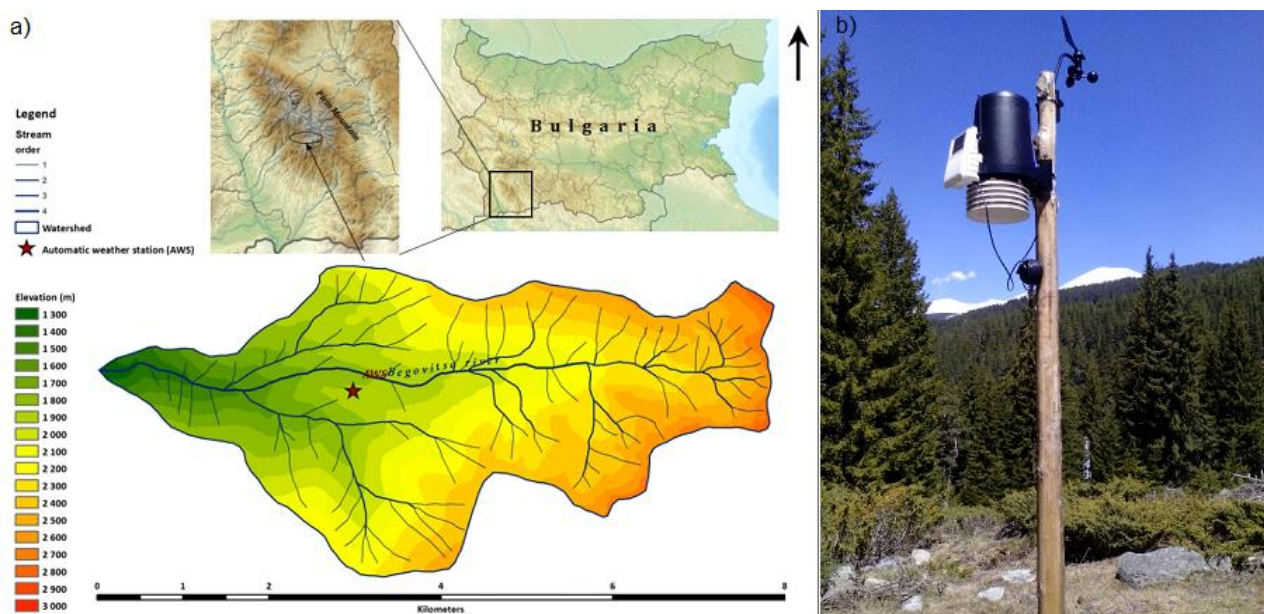
to the favorable temperatures and sunshine, and sufficient precipitation) and negative (frosts, hail, storms, droughts, or floods). Increasing the concentration of CO<sub>2</sub> in the atmosphere may favor the development of a number of plants due to increased processes of photosynthesis (Silva et al., 2016). The increase in temperature leads to the rapid development of plants but can also have an unfavorable effect due to the lack of soil moisture. The results rendered in recent research works (Kunz et al., 2018; Salmon-Albert et al., 2016; Raev et al., 2015; Kramer et al., 2010; Bolte et al., 2010) point out the vulnerability of the European beech to climate change and drought, in particular. Changes in the location of the timberline are also associated with changes in climatic conditions (Knight et al., 2004; Török-Oance & Török-Oance, 2012; Thurm et al., 2018; Pavlovic et al., 2019; Takolander et al., 2019).

Despite of several publications that analyzed climate in various Bulgarian mountains: Stara Planina (Mitkov & Koleva-Lizama, 2019; Nikolova, 2007), Rhodopes (Petkova et al., 2004), Vitosha (Mitkov, 2019), Rila (Nikolova et. al., 2018), Pirin (Grunewald et al., 2009) due to lack of meteorological observations and data, climatological research works in mountainous areas of Bulgaria are insufficient. The present study aims to analyze climate in the southwestern slope of the Pirin Mountains in terms of its favorability for natural vegetation by calculation of eco-climatic indices. The results will contribute to expanding the scope of previous research works related to the climate-vegetation relationship in Bulgaria and the Pirin Mountains, in particular (Bozilova et al., 2004; Atanassova & Stefanova, 2005; Grunewald & Scheithauer, 2008; Grunewald et al., 2009; Raev & Alexandrov, 2011; Raev et. al., 2015).

### Study area, data and methods

The analysed area includes insufficiently studied, in terms of climate, part of the southwestern slope of

the Pirin Mountains. The analyses were based on the daily data recorded by the automatic weather station (AWS) Begovitsa, which is located next to Begovitsa hut. The station was installed in August 2012 (Rachev et al., 2017) at an altitude of 1660 m on the southwestern slope of the Pirin Mountains, in the valley of the Begovitsa River, on a meadow among coniferous vegetation (Fig. 1). The ecoclimatic indices are calculated using monthly data for air temperature and precipitation. Monthly data were obtained by averaging daily data calculated as average from hourly observations. The investigated period covers nine years – from 2013 to 2021. The quality control of the time-series showed missing values for a few days in June 2014, July 2015, May 2017 and August 2019. The missing data were filled in using the data from analogue stations (AWS at hut Yavorov, Sandanski and Musala Peak) by the method of differences (for temperature) and ratios (for precipitation).



**Fig. 1: Study area with the location of the automatic weather station (AWS), a) and AWS, b)**

Ecoclimatic indices are used to study the influence of climate on the territorial distribution of vegetation. In the present study the climate conditions were investigated by the calculation of ecoclimatic indices for the warm part of the year (May – August). For the purpose of the study one temperature index (Mayr tetratherm index – MT) and two indices based on the combination between air temperature and precipitation (monthly De Martonne aridity index – Im, and Compensated Summer Ombrothermic index (CSOi) were used. Since the monthly values of air temperature and precipitation for the period from May

to August are used to calculate Mayr tetratherm and Compensated Summer Ombrothermic indices, in order to compare the results for the individual indices, we calculate monthly De Martonne index for the same months.

#### Mayr tetratherm – MT

Mayr tetratherm is a temperature index which makes possible to establish compliance with the optimal conditions for vegetation during the period with maximum biological activity (Vlăduț, 2010). The value of the index, introduce by Mayr (1909), can be

used to determine the most characteristic vegetation for the temperature conditions for a given area.

Mayr Tetratherm (MT) index is calculated on the basis of average monthly air temperatures according to the formula (Tylkowski et al., 2021):

$$MT = \frac{\sum(t_5 + t_6 + t_7 + t_8)}{4}$$

where  $t_5 + t_6 + t_7 + t_8$  is the sum of the average monthly temperatures for the period May-August.

The period from May to August usually includes the warmest months of the year and therefore Mayr (1909) considers the average monthly temperatures for these months as a limiting factor for the vegetation distribution. The Mayr Tetratherm Index values between 13 and 18°C show that the climate is favorable for the development of beech forests (Satmari, 2010; Bokwa et al., 2021), while according to other authors and the values between 10 and 14°C indicate favourability for coniferous forests, mainly pine trees (Tylkowski, 2015).

#### De Martonne aridity index

De Martonne aridity index (De Martonne, 1926) was used by many authors for the identification of dry or humid conditions in various regions of Europe (Pellicone et al., 2019 – Southern Italy; Baltas, 2007 – Greece, Radaković et al., 2018 – Serbia; Andrade & Corte-Real, 2016 – Iberian Peninsula; Cheval et al., 2015 – South-Eastern Europe, Gavrilov et al., 2020 – Pannonian Basin).

Monthly values of De Martonne index were calculated according to the formula (Satmari, 2010):

$$Im = \frac{12p}{t + 10}$$

where p is the monthly precipitation total and t is the mean monthly air temperature.

The values of the monthly De Martonne index indicate various types of climate – from dry or arid to excessively humid (Table 1).

**Table 1: Climate classification according to monthly values of De Martonne index (Im)**

<b>Im</b>	<b>Climate classification</b>
$I_m < 10$	Dry or arid (D)
$11 \leq I_m \leq 24$	Semiarid (SA)
$24 < I_m \leq 30$	Moderately arid (MA)
$30 < I_m \leq 35$	Slightly humid (SH)
$35 < I_m \leq 40$	Moderately humid (MH)
$40 < I_m \leq 50$	Humid (H)
$50 < I_m \leq 60$	Very Humid (VH)
$60 < I_m \leq 187$	Excessively humid (EH)

Source: Pellicone et al., 2019

#### Compensated Summer Ombrothermic index (CSOi)

For the calculation of Compensated Summer Ombrothermic index (CSOi) the following formula was used (Rivas-Martínez, 1996; Saha et al., 2016):

$$CSO_i = \frac{P_5 + P_6 + P_7 + P_8}{T_5 + T_6 + T_7 + T_8}$$

where:  $P_5 + P_6 + P_7 + P_8$  is the sum of monthly precipitation for the period May – August in mm, and  $T_5 + T_6 + T_7 + T_8$  is the of monthly average air temperature for the period May – August in °C.

The classification of the climate type according to the ombrothermic index is given at Table 2.

**Table 2: Climate classification according to the ombrothermic index**

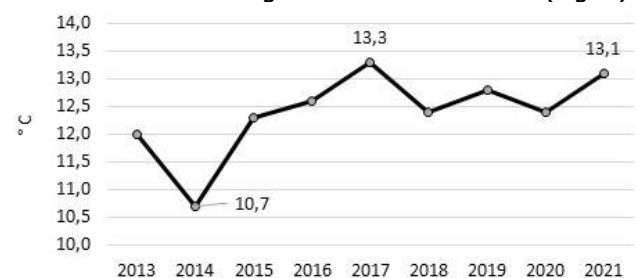
<b>Ombrothermic index</b>	<b>Climate type</b>
0.1 - 0.3	Hyper arid
0.3-0.9	Arid
0.9-2.0	Semi-arid
2.0-3.0	Dry
3.0-5.5	Subhumid
5.5-11	Humid

Source: Vlăduț et al., 2017

## Results and discussion

### Mayr tetratherm – MT

Mayr tetratherm index is an indicator for the temperature conditions during the warmest months of the year. The results of the calculations show that, for the period 2013 – 2021, the index varies between 10.7 and 13.3°C with an average value of 12.4°C, which characterizes the investigated region as favorable for coniferous trees, which have lower thermal requirements compared to deciduous species. The average May – August temperature was lowest in 2014 and highest in 2017 and 2021 (Fig. 2).



**Fig. 2: Mayr tetratherm index**

The climatic conditions for the vegetation development are determined not only by temperature, but also by the humidity conditions, which are analyzed in this article by the De Martonne aridity index and Compensated Summer Ombrothermic index (CSOi).

### De Martonne aridity index

Due to the variability of monthly precipitation and temperature during the investigated period high variability of monthly values (May – August) of De Martonne index was established. For the study area, the monthly amount of precipitation is essential when calculating the De Martonne index. The average

monthly values of the temperature are of less importance, because in the middle mountain belt, where the study station is located, high average temperatures cannot be observed. However, for some of the months in which the monthly amount of precipitation was quite low, extremely low values of the De Martonne Index were obtained (Table 3). The highest value was observed in June 2013 and the lowest was in July 2021. According to this result the climate conditions in the region for the study period varied from excessively humid to arid. It is an interesting fact that in one year (2013) the highest and some of the lowest values are observed. In the recent years, low values of the De Martonne Index have been established, due to the increase in dry months on the one side, and on the other side, to the higher average monthly temperatures. Similar conditions in other Bulgarian mountains were reported by Nikolova (2007), Nikolova et al. (2018) and Mitkov (2019).

**Table 3: Monthly values of the De Martonne Index (mm/°C) for the period 2013 – 2021 (May– August)**

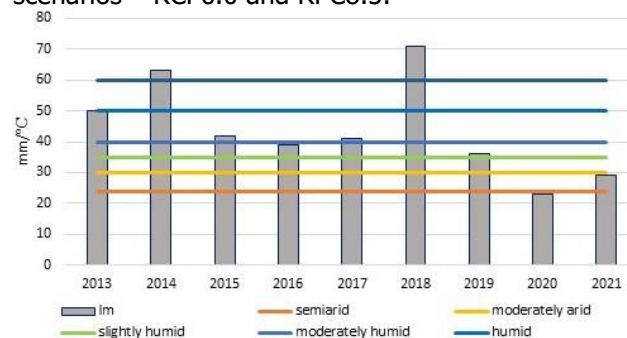
Year	May	Climate	June	Climate	July	Climate	August	Climate
2013	43	H	107	EH	46	H	4	A
2014	95	EH	46	H	60	EH	49	H
2015	34	SH	70	EH	34	SH	29	MA
2016	91	EH	15	SA	23	SA	26	MA
2017	44	H	46	H	43	H	30	MH
2018	99	EH	95	EH	67	EH	21	SA
2019	61	EH	40	H	33	HH	11	SA
2020	48	H	17	SA	22	SA	4	A
2021	37	MH	64	EH	3	A	13	SA
Average	61	EH	56	VH	37	MH	21	SA

According to the average monthly values of the De Martonne index for the period 2013 - 2021, the climatic conditions change from excessively humid in May to semiarid in August (Table 3). The obtained results are regular in relation to the intra-annual distribution of the average monthly temperatures and the monthly precipitation amounts, typical for Southwestern Bulgaria. The low value in August is also not surprising given the great Mediterranean influence in this part of the country (Rachev and Dinkov, 2003).

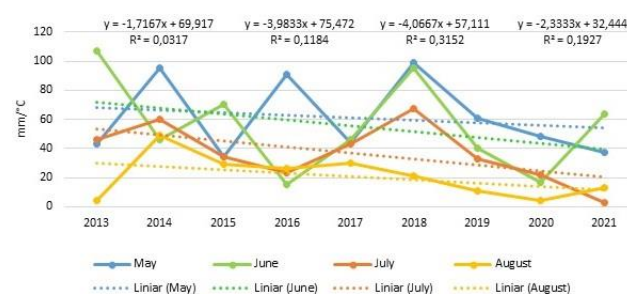
The averaging of the monthly values by years makes possible the determination of the conditions of humidity for the period May-August for each of the studied years. The results show that the years with moderately humid and humid conditions in the period May - August prevail (Fig. 3). The years 2014 and 2018 display excessively humid conditions, while semiarid and moderately arid conditions correspond to May – August interval mostly in 2020 and 2021.

Even if the analysed period is quite short, the values of the monthly De Martonne index display a downward trend for all the months included in the warm interval, the most significant decrease being registered by July (Fig. 4). This is consistent with the

information rendered in IPCC reports (2014, 2021) regarding the evolution of future climate in the Balkan area – harsher aridity conditions especially during summer months. In this context, which however depends on future CO<sub>2</sub> emissions, forests will be affected even within this mountainous area. At RCP8.5, temperature increase is certain (high confidence), no matter the time span, but it is also expected a significant change in total precipitation amounts and in their regime – higher amounts during winter and a substantial reduction in summer months (Integrated Drought Management Programme in Central and Eastern Europe, 2014). In current conditions, the forests in the area have a low vulnerability level based on De Martonne index, but the optimal moisture conditions will change and forest vulnerability will increase by 2050, respectively 2070 even at RCP4.5, vulnerability and affected surface gradually increasing for the other two less optimistic scenarios – RCP6.0 and RCP8.5.



**Fig. 3: Averaged monthly (May – August) De Martonne aridity index**



**Fig. 4: Monthly values of De Martonne aridity index and their evolution trends**

### Compensated Summer Ombrothermic index (CSOi)

In the area of the studied station, for both the De Martonne index and the ombrothermic index, the monthly precipitation amounts for the months of May-August are essential, while the average temperatures have lower impact due to the limiting factor of altitude. The values of the Compensated Summer Ombrothermic index (Table 4) in most of the cases show climatic conditions close to those established based on the De Martonne index. The highest values



of the CSOi are established for the years 2018 and 2014, when the summer precipitation was the highest for the studied period.

**Table 4: Compensated Summer Ombrothermic index for the period 2013 – 2021 (°C)**

	2013	2014	2015	2016	2017	2018	2019	2020	2021	Average
CSOi	7.4	9.7	6.2	5.2	5.9	10.3	5.1	3.2	3.9	6.3
Climate type	Humid	Humid	Humid	Subh.	Humid	Humid	Subh.	Subh.	Subh.	Humid

According to the average value of the CSOi for the period 2013 - 2021, the climate in the region of the station can be defined as humid. The CSOi, as well as the De Martonne index, shows a relatively large variation of the values in individual years - from 3.2°C in 2020 to 10.3°C in 2018, which means a climate closer to dry conditions in the first case and a humid climate in 2018. However, of the four subhumid years, three correspond to the last years included in the analysed period.

## Conclusion

The present study shows the results of the meteorological monitoring organized on the southwestern slope of the Pirin Mountains (Bulgaria), analysing the influence of climatic conditions on the distribution of the natural vegetation.

Based on one temperature index (Mayr tetratherm) and two indices which combine temperature and precipitation (De Martonne aridity index and Compensated Summer Ombrothermic index), the temperature and humidity conditions for the warm period (May to August) are characterized. It was found that in most of the studied years the climate was humid, which in combination with the results of the calculation of the Mayr tetratherm index shows that the climatic conditions in the area are favourable for the development of coniferous forests.

The annual course and the inter-annual variability in air temperature and precipitation determine large variations in the De Martonne and the Compensated Summer Ombrothermic indices. The values of these indices depend more on the monthly amounts of precipitation than on changes in the temperature. In the last two years, due to the drier summer months, there has been a manifestation of arid climates.

Due to the short observation period (2013-2021), it is difficult to identify a trend in climate change, but the results show specific features of the climate in the investigated area and can serve as a basis for further research to answer the questions about climate change in the mountainous regions of Bulgaria and the influence of the climate on the distribution of the natural vegetation. In the future, the scope of research will be expanded to include data on winter rainfall, which is an important factor in providing the necessary moisture for plants.

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