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CLIMATE AND ITS CHANGES IN THE PERIOD 1979–2018 IN SELECTED MODEL KARST REGIONS IN BULGARIA

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This study reveals the climate and its changes in the period 1979–2018 in the following karst regions in Bulgaria - Devetashko Plateau, Brestnishka Karst Geosystem, Trigrad, Dabrash and Shumensko Plateau. Statistical methods are the main tool in this research. The climate of the five model karst regions is largely dependent on their location, especially on their altitude. A widespread rise in air temperatures and evaporation is observed in the months of the warm half-year. Precipitation increases mainly in September and October, and decreases in August.

Keywords: climate change, Bulgaria, karst regions, trends

КЛИМАТ И НЕГОВИТЕ ПРОМЕНИ В ПЕРИОДА 1979–2018 Г. В ИЗБРАНИ МОДЕЛНИ КАРСТОВИ РАЙОНИ В БЪЛГАРИЯ

Петър Ножаров

Резюме: Това изследване разкрива климата и неговите промени в периода 1979–2018 г. в избрани моделни карстови райони в България. Моделните карстови райони са Деветашко плато, Брестнишка карстова геосистема, Триград, Дъбраш и Шуменско плато. Използват се основно статистически методи. Климатът на петте моделни карстови района до голяма степен зависи от тяхното местоположение и най-вече от надморската им височина. Трите сравнително ниско разположени района в Северна България се характеризират с по-високи температури на въздуха, умерени валежи и по-голямо изпарение. Това води до по-дълъг период, приблизително половин година, на отрицателни стойности (недостиг на вода) на разликата между валежите и изпарението. Съответно средногодишните стойности на тази разлика са малко над нулата, което все още харак-

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теризира тези райони като такива с малък воден излишък. Двата южни и по-високо разположени района в Родопите имат по-ниски температури на въздуха, по-високи валежи, по-ниско изпарение и съответно по-високи стойности на разликата валежи–изпарение. Това ги прави източници на вода през три четвърти от годината. Средногодишните стойности на тази разлика са значително по-високи от тези на останалите три района в Северна България. От гледна точка на тенденциите има широко разпространено покачване на температурите на въздуха през месеците от топлото полугодие. Наблюдава се също значимо увеличение на средногодишните температури на въздуха. Трендовете при изпарението са подобни на тези при температурите на въздуха. Валежите се увеличават главно през септември и октомври, а намаляват през август. Средногодишните стойности не показват значими тенденции. Разликата валежи–изпарение следва тенденциите при валежите. Не се наблюдават значителни промени в приведеното към морско равнище атмосферно налягане. Въз основа на трендовете при средногодишните стойности, където има значимо повишаване на температурата на въздуха и няма изменение на валежните количества, може да се заключи, че процесите в карстовите райони като цяло би следвало да увеличават интензивността си.

Ключови думи: климатични промени, България, карстови райони, тенденции

INTRODUCTION

One of the major global processes in the last century has been climate warming, which is caused mainly by the increase in greenhouse gases (Bindoff et al., 2013). According to the latest, fifth IPCC report (Hartmann et al., 2013), the rise in global air temperature is 0.85°C for the period 1880-2012 and 0.72°C for the period 1951–2012. Similar tendencies are observed also in Bulgaria (Nojarov, 2014; Nojarov, 2019). The climate change has various manifestations at regional level, mainly changes in atmospheric circulation such as increasing of the width of the tropical belt (Seidel et al., 2008; Forster, 2011), poleward moving of jet streams in the northern hemisphere (Fu et al., 2006; Hu and Fu, 2007; Strong and Davis, 2007), etc. These changes in turn lead to changes in precipitation, atmospheric pressure, cloudiness, solar radiation, direction of transport of air masses, wind and other climatic elements. In Bulgaria, there have been serious changes in intra-annual course of precipitation (Drenovski and Stoyanov, 2009, 2010) which are caused by changes in atmospheric circulation (Nojarov, 2017a; Nojarov, 2017b). The gas composition of and aerosols in the atmosphere over Bulgaria (the same as in other locations around the world) has a serious influence on elements such as radiation fluxes at earth‘s surface and air temperature (Che et al., 2018; Derimian et al., 2016; Chou et al., 2006). A few works in recent years show that greenhouse gases (water vapor, CO_2, CH_4) in the atmosphere over Bulgaria are increasing and the amount of aerosols is decreasing (Nojarov, 2016).

There are many studies worldwide that link climate change and conditions in karst territories, including caves. A number of articles have highlighted the link between climate change (mainly precipitation amounts and evaporation) and caves/karst systems as sources of water for the population living there (Jia et al., 2017; Loaiciga et al., 2000; Sarrazin et al., 2018). Some of these studies focus on the relationship between climate change and quality (mineralization) of water supplied by karst systems (Khaska et al., 2017; Jeannin et al., 2016). Other articles deal with the relationship between changes in atmospheric air temperature and changes in air temperature in caves, which also lead to changes in the ventilation regime (and, accordingly, the gas composition) of the caves (Badino, 2004; Peyraube et al., 2017). There are less studies that assess in complex the impact of different climatic elements on different elements of the karst system/cave (Pipan et al., 2019). In Bulgaria, there is research on the relationship between atmospheric air temperature and air temperature in caves (Stoeva and Stoev, 2005), cave microclimate (Maglova et al., 2004; Stoev and Cholakov, 1983; Kyurkchiev, 2019) and in recent years a complex approach has been developed to investigate karst systems and caves (Andreychuk and Stefanov, 2006; Stefanov, 2013).

The aim of this study is to reveal the climate, through some of its main elements, and its changes in the period 1979–2018 in selected model karst regions in Bulgaria. The model karst regions are five: Devetashko Plateau, Brestnishka Karst Geosystem, Trigrad, Dabrash and Shumensko Plateau (Figure 1). Studied climatic elements include air temperature, precipitation, evaporation, difference between precipitation and evaporation, and sea level pressure (SLP). The main tasks to achieve this aim are to reveal the intra-annual course of the studied climatic elements in the five model karst regions and to identify the trends in the period 1979–2018. The aim and tasks of this study are based on the idea that these climatic elements are very important for the processes occurring in karst systems/caves.

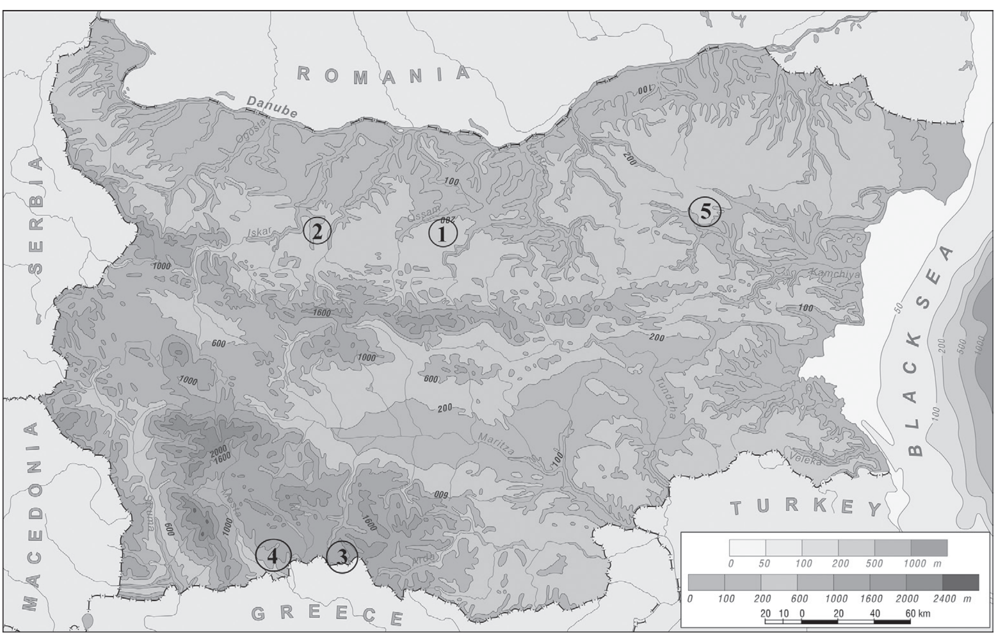

Fig. 1. Location of the model karst regions in Bulgaria 1– Devetashko Plateau;
2 – Brestnishka Karst Geosystem; 3 – Trigrad; 4 – Dabrash; 5 – Shumensko Plateau

DATA AND METHODS

Two meteorological stations from the National Institute of Meteorology and Hydrology system - Pleven and Lovech – are a source of primary climatic information, which includes air temperature and precipitation. Mean monthly data for these two elements are used for the entire study period, which coincides temporally with the reanalysis data. Spatially, these are the closest meteorological stations located near the Devetashko Plateau and are included mainly to reveal if there is a good agreement with the reanalysis data, which in this and further studies will be leading as they cover areas where there are no currently operating meteorological stations. Mean monthly data from The European Center for Medium-Range Weather Forecasts (ECMWF), ERA5 reanalysis (Copernicus Climate Change Service (C3S), 2017) were used for all studied regions. The resolution of these data is 0.25 x 0.25° (30 x 30 km) and their period is 1979–2018. This period is long enough to show the climate and its current trends in the studied model regions. Reanalysis data include air temperature, precipitation, SLP and evaporation, the latter allowing to calculate the water which remains available in a given region after evaporation. In accordance with the resolution of the reanalysis, the cells, which cover the respective model karst regions, are as follows: Devetashko Plateau is covered by two cells 43-43.15°N, 24.45-25°E and 43-43.15°N, 25-25.15°E; Brestnishka Karst Geosystem is covered by two cells 42.45-43°N, 24-24.15°E and 42.45-43°N, 24.15-24.30°E; Trigrad is covered by one cell 41.30-41.45°N, 24.15-24.30°E; Dabrash is covered by one cell 41.30-41.45°N, 23.45-24°E; Shumensko Plateau is covered by two cells 43-43.15°N, 26.45-27°E and 43.15-43.30°N, 26.45-27°E.

This study uses mainly statistical methods (Wilks, 2006). The level of statistical significance for all calculations is $p < 0.05$. The trend analysis was done by means of linear regression. The linear regression represents the relationship between the independent variable (time) and the dependent variable (different climatic variables - air temperature, precipitation, etc.) through a linear equation based on the observed values. Also, monthly average values for the entire studied period based on monthly averages of the different climatic elements were calculated for the five model karst regions, which makes it possible to create a spatial and intra-annual characteristic of the different climatic elements.

RESULTS AND DISCUSSION

DEVETASHKO PLATEAU REGION

Figure 2 shows the intra-annual course of air temperature, precipitation, evaporation and the difference precipitation-evaporation in the region Devetashko Plateau. Precipitation, evaporation, and their difference are shown through their average monthly values for correct comparison of the months of the year. Air temperature has course with a maximum in July (22.8°C) and a minimum in January (-0.2°C). Precipitation maximum is in May and the secondary one is in December, and the minimum is in February and the secondary one is in October. Since evaporation is measured in negative values the higher negative values indicate higher evaporation and vice versa. That is why it has a maximum in June and a minimum in January. This course largely follows the intra-annual air temperature course. Precipitation-evaporation difference

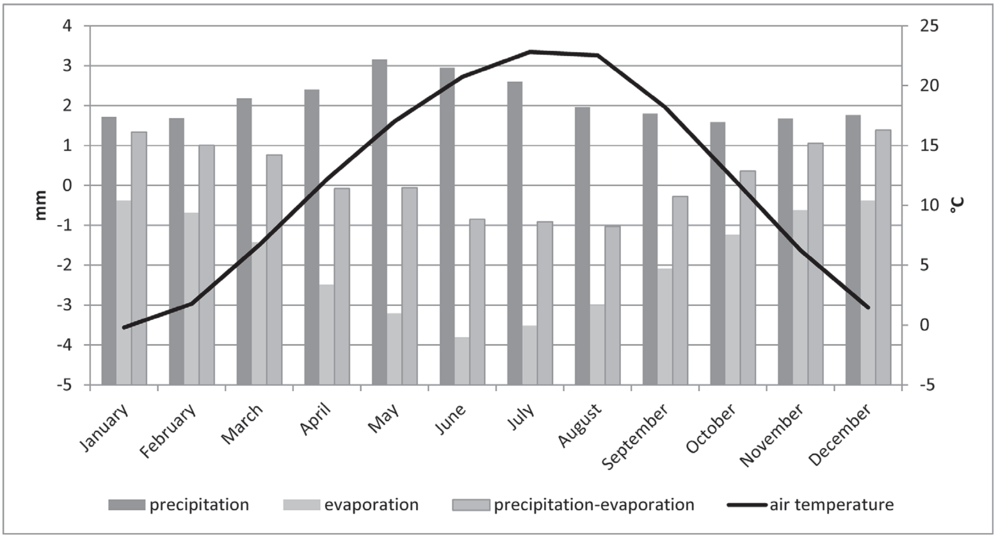

Fig. 2. Intra-annual course of air temperature (in °C, right Y-axis), precipitation (in mm, left Y-axis), evaporation (in mm, left Y-axis) and the difference precipitation-evaporation (in mm, left Y-axis) in the region Devetashko Plateau for the period 1979–2018

is highest in December (positive, 1.4 mm) and smallest in August (negative, -1 mm). As a whole, there is a water surplus in the region in the period October-March, and in the rest of the year the balance is negative, i.e. there is a water shortage that could be replenished from other regions. On an average annual basis, for the period 1979-2018, Devetashko Plateau has a positive precipitation-evaporation balance of 0.2 mm. This means that the area is generally a source of water.

Figure 3 shows a climatogram of the meteorological station Lovech for the period 1979–2018 and it includes only air temperature and precipitation, since only these data are available. Air temperature maximum is in July (23.2°C) and the minimum is in January (0.3°C). These values are slightly higher than those shown in Figure 2, due to the local physico-geographic conditions typical for the location of the meteorological station. In the course of the study, an inhomogeneity in the series of air temperatures at Lovech station was found, when compared to station Pleven, which is homogeneous during the studied period. The finding was that there are two sharp jumps in air temperature at Lovech station, the first one between 2000 and 2001 and the second one between 2008 and 2009. Accordingly, the periods before 2009 were adjusted to the last period (2009–2018) through the method of differences with station Pleven. Precipitation series during the studied period are homogeneous, having intra-annual course with maximum in July and a secondary one in September, while the minimum is in February and the secondary one is in August. Here, too, there are differences with Figure 2, but generally precipitation has greater spatial variability, which explains these differences.

Figure 4 shows a climatogram of the meteorological station Pleven, which includes the available data on air temperature and precipitation. Air temperature maximum is in July (23.8°C) and the minimum is in January (-0.1°C). It could be seen

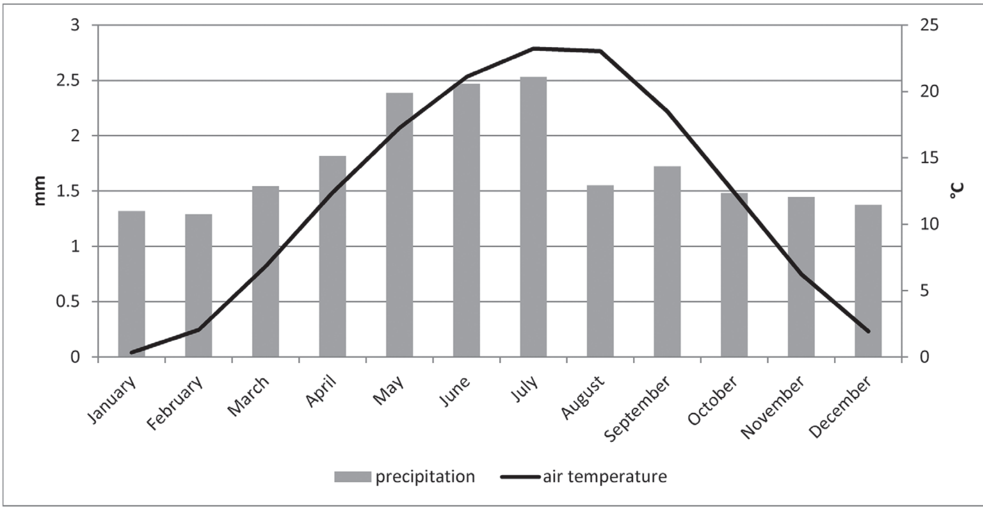

Fig. 3. Intra-annual course of air temperature (in °C) and precipitation (in mm) at Lovech station for the period 1979–2018

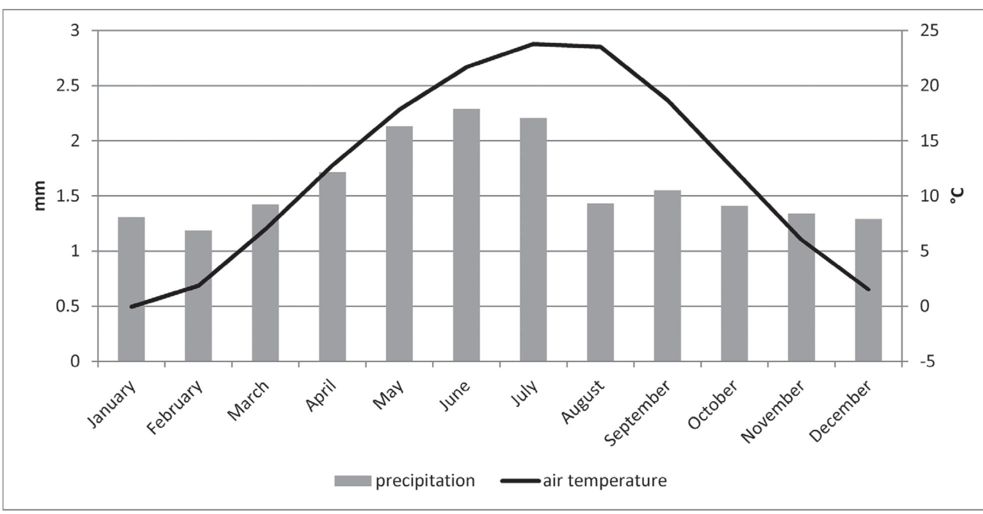

Fig. 4. Intra-annual course of air temperature (in °C) and precipitation (in mm) at Pleven station for the period 1979–2018

that the main difference with Figure 2 is in July, but this should be expected since Pleven is located lower than Devetashko Plateau and especially in summer the air temperature is higher. Precipitation maximum is in June and the secondary ones are in September and January, while the minimum is in February and the secondary ones are in August and December. Here, there are also some differences with Figure 2, which are largely explained by the spatial variability of precipitation amounts.

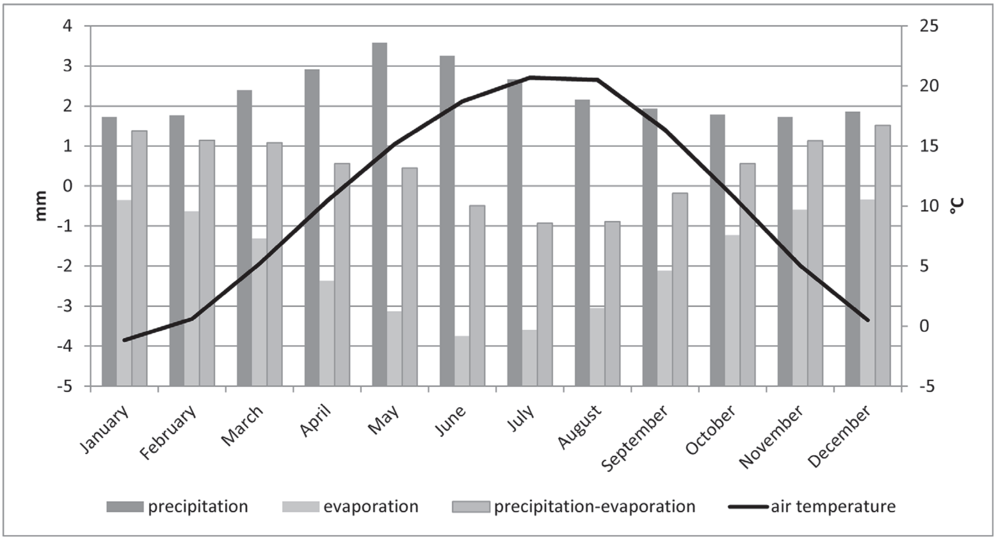

Fig. 5. Intra-annual course of air temperature (in °C, right Y-axis), precipitation (in mm, left Y-axis), evaporation (in mm, left Y-axis) and the difference precipitation-evaporation (in mm, left Y-axis) in the region Brestnishka Karst Geosystem for the period 1979–2018

BRESTNISHKA KARST GEOSYSTEM REGION

Figure 5 shows the intra-annual course of air temperature, precipitation, evaporation and the difference precipitation-evaporation in the region Brestnishka Karst Geosystem. Air temperature maximum is in July (20.7°C) and the minimum is in January (-1.2°C). These temperatures are lower compared to Devetashko Plateau due to the higher altitude of this region. Precipitation maximum is in May and the secondary one is in December, while there are two equivalent minima in November and January. Evaporation minimum is in December and the maximum is in June, largely following the course of air temperature. The precipitation-evaporation difference maximum is in December (positive, 1.5 mm) and the minimum is in July (negative, -0.9 mm). The period when this region has water surplus is from October to May, and water shortage is observed in the period June-September. On an annual basis, for the period 1979–2018, Brestnishka Karst Geosystem has a positive precipitation-evaporation balance of 0.4 mm. This region is also a source of water, with values approximately twice as much as Devatashko Plateau region.

TRIGRAD REGION

Figure 6 shows the intra-annual course of air temperature, precipitation, evaporation and the difference precipitation-evaporation in Trigrad region. Air temperature maximum is in July (16.6°C) and the minimum is in January (-3.2°C). These temperatures are significantly lower compared to the previous two model karst regions due to the higher altitude of this region. Precipitation maximum is in May and the

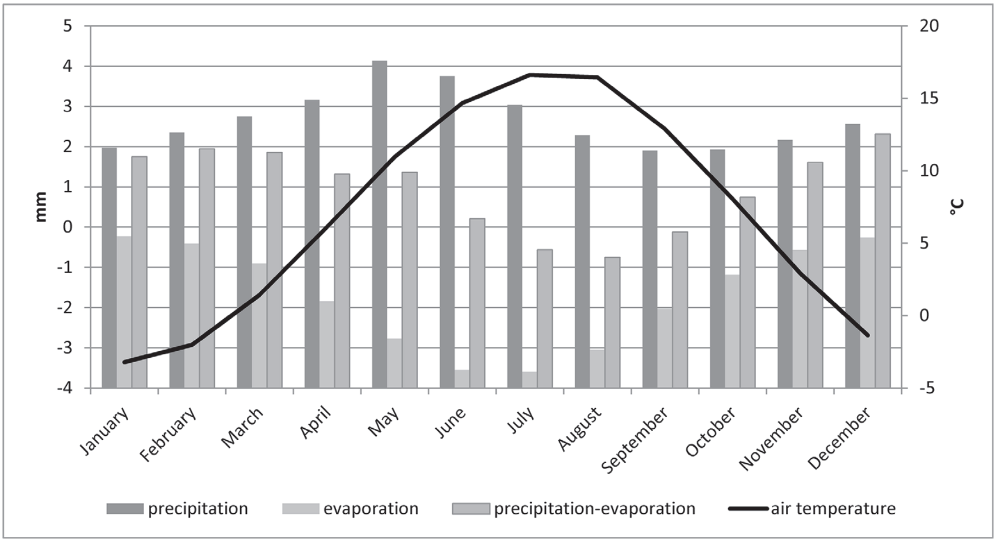

Fig. 6. Intra-annual course of air temperature (in °C, right Y-axis), precipitation (in mm, left Y-axis), evaporation (in mm, left Y-axis) and the difference precipitation-evaporation (in mm, left Y-axis) in Trigrad region for the period 1979–2018

secondary one is in December, while the minimum is in September and the secondary one is in January. Evaporation maximum is in July and the minimum is in January (in sync with air temperature). The precipitation-evaporation difference maximum is in December (positive, 2.3 mm), and the secondary maximum is in February (positive, 2 mm), and the minimum is in August (negative, -0.8 mm) and the secondary one is in January (positive, 1.8 mm). The period of water surplus in this region lasts from October to June, and water shortage period is from July to September. On average annual basis, for the period 1979 -2018, the Trigrad region has a positive precipitation-evaporation balance of 1 mm. This value is about 5 times higher than the Devatashko Plateau one, which indicates that this region in the Rhodopes is a significant source of water during almost the entire year (excluding three months).

DABRASH REGION

Figure 7 shows the intra-annual course of air temperature, precipitation, evaporation and the difference precipitation-evaporation in Dabrash region. Air temperature maximum is in July (16.5°C) and the minimum is in January (-3.6°C). These temperatures are similar to those in the nearby Trigrad region. Precipitation maximum is in May and the secondary one is in December, while the minimum is in September and the secondary one is in January. Evaporation maximum is in July and the minimum is in December. The precipitation-evaporation difference maximum is in December (positive, 2.8 mm) and the secondary maximum is in February (positive, 2.4 mm), and the minimum is in August (negative, -0.4 mm) and the secondary one

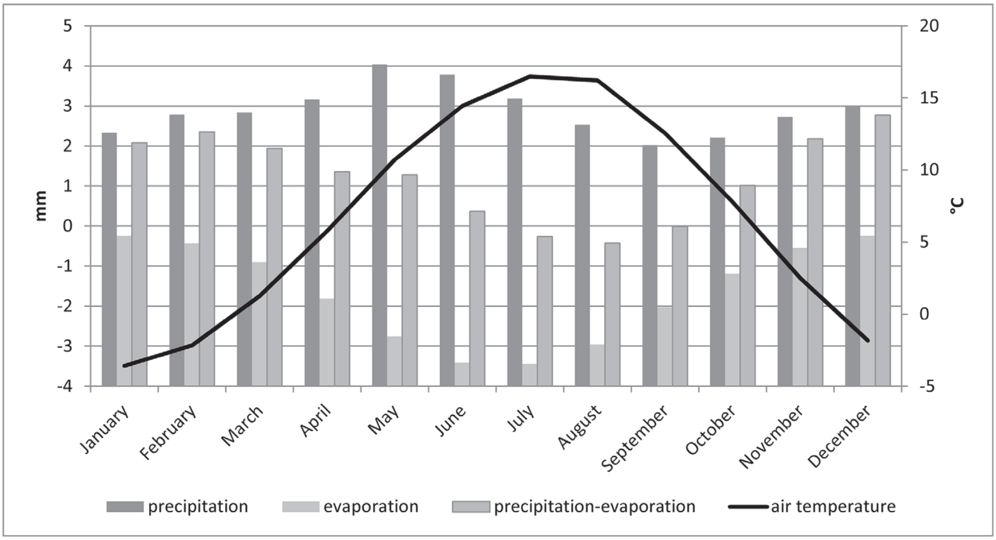

Fig. 7. Intra-annual course of air temperature (in °C, right Y-axis), precipitation (in mm, left Y-axis), evaporation (in mm, left Y-axis) and the difference precipitation-evaporation (in mm, left Y-axis) in Dabrash region for the period 1979–2018

is in January (positive, 2.1 mm). The period of water surplus in the region lasts from October to June, and the period with water shortage is from July to September. On average annual basis, for the period 1979–2018, the Dabrash region has a positive precipitation-evaporation balance of 1.2 mm. Thus, this region (similarly to Trigrad) is a significant source of water during almost the entire year (except for three months).

SHUMENSKO PLATEAU REGION

Figure 8 shows the intra-annual course of air temperature, precipitation, evaporation and the difference precipitation-evaporation in the region Shumensko Plateau. Air temperature maximum is in July (22°C) and the minimum is in January (-0.1°C). Precipitation maximum is in June and the minimum is in August. During the period September-February an almost uniform distribution of precipitation with slightly expressed maxima and minima is observed. Evaporation maximum is in June and the minimum is in January. The precipitation-evaporation difference maximum is in January (positive, 1.4 mm) and the minimum is in July (negative, -1.3 mm). The water surplus period here lasts from October to March, and the period of water shortage is from April to September. On average annual basis, for the period 1979 - 2018 the region Shumensko Plateau has a positive precipitation-evaporation balance of 0.1 mm. In general, this region can also be considered as a source of water, but it has the lowest value of this indicator compared to the other model karst regions. This is largely due to its relatively low altitude and its location in an area with lower precipitation amounts.

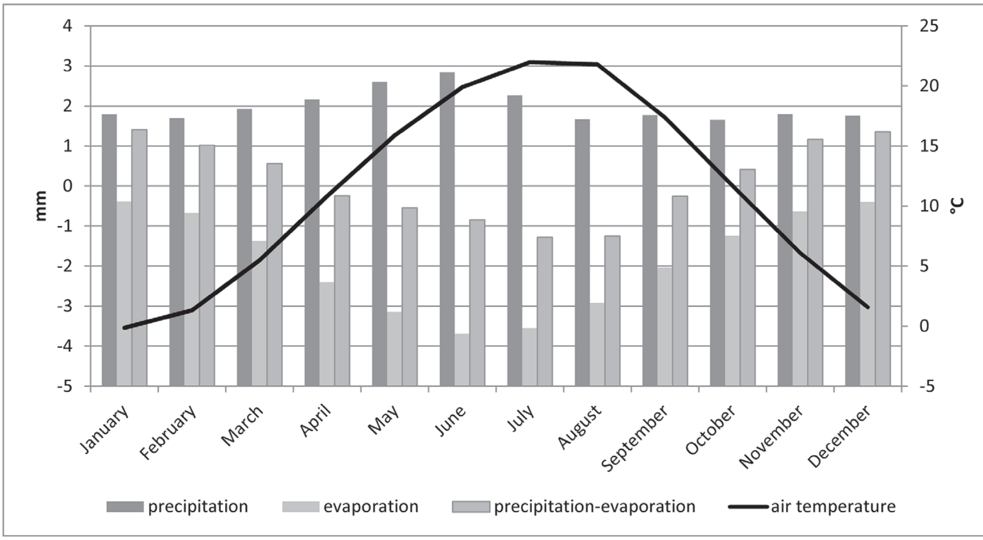

Fig. 8. Intra-annual course of air temperature (in °C, right Y-axis), precipitation (in mm, left Y-axis), evaporation (in mm, left Y-axis) and the difference precipitation-evaporation (in mm, left Y-axis) in the region Shumensko Plateau for the period 1979–2018

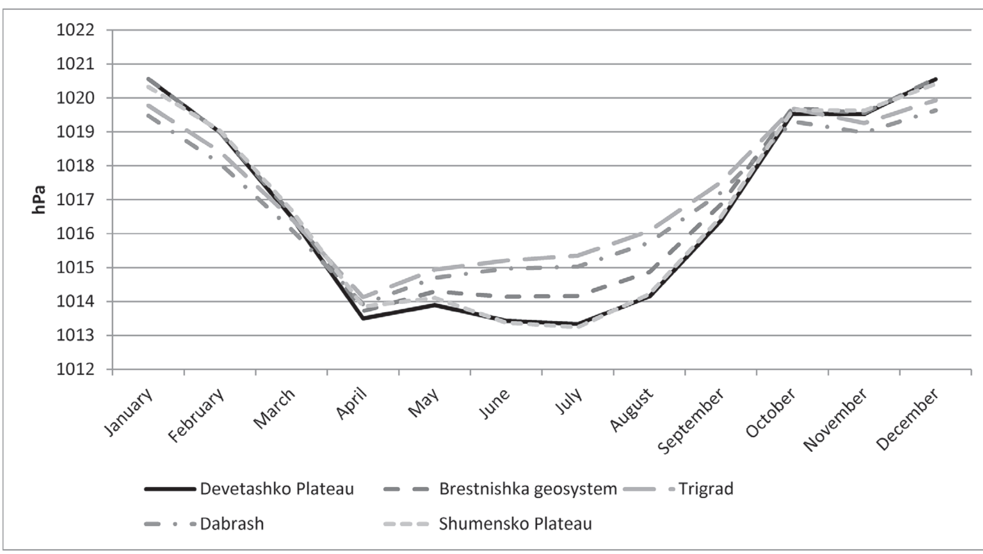

Fig. 9. Intra-annual course of sea level pressure (in hPa) in the five model karst regions for the period 1979–2018

SEA LEVEL PRESSURE

Figure 9 shows the intra-annual SLP course in the five model karst regions for the period 1979–2018. SLP is one of the main indicators characterizing atmospheric circulation over a given region. For its part, it exerts essential impact on other climatic elements such as precipitation, wind, air temperature, etc. Also, SLP influences ventilation regimes in the caves and hence the other elements of cave microclimate. Overall, the figure shows that SLP has a course with one basic minimum for all studied regions, which is in April, and the three regions with lower altitude have another minimum in July. The main maximum everywhere is in December, and the secondary one is in October. During the cold half-year (October–April), no significant differences in SLP values are observed in the five model karst regions. In the warm half-year, the regions with higher altitude have higher SLP due to the stratification of the atmosphere during that part of the year, when air temperature is higher and there is a normal lapse rate.

TEMPORAL CHANGES IN THE DIFFERENT CLIMATIC ELEMENTS

Table 1 shows the trends in air temperatures in the model karst regions and meteorological stations in the period 1979–2018. In this way, current tendencies in the studied climatic element can be traced. It could be seen that the average annual air temperatures are increasing everywhere, and this increase is statistically significant. Specific values range from 0.3 to 0.5 °C/decade. This increase is mainly due to the increase in air temperatures in summer, and also to the increase in spring months in the higher and southern regions (Trigrad and Dabrash). There is also a widespread rise in air temperatures in November. These trends are in good agreement with previous studies on the territory of Bulgaria (Nojarov, 2014, 2019). The increase in air temperatures in November is due also to the circulation factor as a result of the change of location of major circulation centers affecting the weather and climate of Bulgaria.

Table 1.

Trends (per decade) in air temperature (°C) in the model karst regions and meteorological stations in the period 1979-2018. Statistically significant trends (at p <0.05, where ***p*** *is significance) are bolded*

	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Annual**
Devetashko Plateau	0.2	0.7	0.5	**0.6**	0.4	**0.4**	**0.6**	**0.7**	0.2	0.1	**0.8**	0	**0.4**
Brestnishka geosystem	0.2	0.7	0.5	**0.6**	0.3	**0.3**	**0.6**	**0.7**	0.1	0.1	**0.7**	0.1	**0.4**
Trigrad	0.4	**1**	**0.7**	**0.6**	**0.4**	**0.3**	**0.6**	**0.7**	0.2	0.2	**0.7**	0.3	**0.5**
Dabrash	0.4	**0.8**	**0.6**	**0.7**	**0.4**	**0.4**	**0.6**	**0.7**	0.2	0.2	**0.7**	0.4	**0.5**
Shumensko Plateau	0.1	0.7	0.6	**0.5**	**0.4**	**0.4**	**0.7**	**0.9**	0.3	0.1	**0.8**	0	**0.5**
Lovech	0.1	0.6	0.5	0.4	0.2	0.2	**0.4**	**0.6**	0	0	**0.7**	0	**0.3**
Pleven	0.1	0.6	0.5	0.4	0.1	0.2	0.4	**0.5**	0	0	**0.7**	0	**0.3**

Table 2 shows precipitation trends in the model karst regions and meteorological stations in the period 1979–2018. Overall, no statistically significant trends are observed in the average annual values, i.e. there has been no change in precipitation amounts over the last four decades. However, there are some differences in the average monthly values. An increase in precipitation is observed in all regions in September and October, and half of the values are statistically significant. This trend, as well as the causes explaining it (changes in atmospheric circulation manifested in a poleward shift of the Azores High, a decrease of sea level pressure and an increase in the number or intensity of cyclones) have already been addressed in the article by Nojarov (2017b) (for Mediterranean and Black Sea basins). In the two higher and southern regions (Trigrad and Dabrash) a statistically significant increase has been also revealed in March. This is a trend which has not been observed in the period 1950–2012 (Nojarov, 2017a), which means that in the period before 1979, the precipitation during this month was higher and in the last decades there has been a recovery towards these higher values. There are widespread negative trends in August and November, and some of them are statistically significant. The November trends are confirmed by previous study (Nojarov, 2017a), which shows their persistence, while those in August do not coincide, which means that in the period before 1979 the August precipitation was lower and in the last decades it again has been recovering towards current values. The revealed different trends in the different months of the year will lead to changes in intra-annual precipitation course, which will also influence the processes in the model karst regions.

Table 2.

*Trends (per decade) in precipitation (average monthly and average annual, in mm) in the model karst regions and meteorological stations in the period 1979–2018. Statistically significant trends (at p <0.05, where **p** is significance) are bolded*

	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Annual**
Devetashko Plateau	0.1	0.1	0.1	-0.1	-0.1	-0.1	0.1	**-0.4**	0.3	**0.3**	-0.2	0	0
Brestnishka geosystem	0.2	0.1	0.2	0	-0.1	0	0.1	-0.3	0.3	**0.3**	-0.2	0	0.1
Trigrad	0.2	0.2	**0.3**	-0.1	-0.1	0.3	-0.2	**-0.4**	**0.3**	0.3	-0.2	0	0
Dabrash	0.2	0.2	**0.4**	-0.2	-0.1	0.1	-0.2	**-0.5**	0.3	0.2	-0.2	0	0
Shumensko Plateau	0.2	0.1	0.1	-0.2	0	-0.1	-0.1	-0.2	0.2	0.2	-0.1	0.1	0
Lovech	0	0.1	0.1	-0.1	0	0.1	0.2	-0.1	**0.4**	**0.3**	**-0.2**	0.1	0.1
Pleven	0	0.1	0.2	0	0	-0.2	0.2	-0.1	**0.4**	**0.4**	-0.2	0.1	0.1

Table 3.

*Trends (per decade) in evaporation (average monthly and average annual, in mm) in the model karst regions in the period 1979-2018. Statistically significant trends (at p <0.05, where **p** is significance) are bolded*

	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Annual**
Devetashko Plateau	0	-0.02	-0.06	**-0.07**	-0.05	**-0.08**	-0.07	-0.06	0.05	0	-0.02	0.01	**-0.03**
Brestnishka geosystem	-0.01	-0.03	-0.06	**-0.07**	**-0.08**	**-0.09**	-0.06	-0.08	0.04	0	-0.03	0	**-0.04**
Trigrad	-0.02	**-0.04**	**-0.1**	**-0.1**	**-0.1**	**-0.07**	**-0.07**	-0.04	**0.06**	0	-0.02	**-0.04**	**-0.04**
Dabrash	-0.03	-0.04	**-0.1**	**-0.1**	**-0.07**	-0.05	**-0.04**	-0.04	0.02	-0.01	**-0.02**	**-0.03**	**-0.04**
Shumensko Plateau	0	-0.03	**-0.07**	**-0.07**	-0.04	-0.03	-0.03	0.02	**0.08**	0.02	-0.01	0.01	-0.01

Table 3 shows trends in evaporation in the model karst regions in the period 1979–2018. Since evaporation has negative values, the negative trends here indicate an increase in evaporation and vice versa. In this sense, there are negative trends in the average annual values, which means an increase in evaporation. In four of the five studied regions, these trends are also statistically significant. This is largely explained by the observed increase in air temperatures. There are widespread negative trends in spring and summer monthly averages, most of which are statistically significant. This is also in agreement with trends in air temperatures during these months. Positive trends, some of which are statistically significant, are observed only in September, due to the increase in cloudiness and precipitation (Nojarov, 2015, 2017b).

Table 4 shows trends in precipitation-evaporation difference in the model karst regions in the period 1979–2018. This indicator shows how much water remains in a given region after evaporation of a certain part of precipitation. It could be seen that there is no trend in average annual values. It should be noted that precipitation is the leading term in this indicator since the evaporation trends are of order of magnitude smaller. The average monthly values show widespread negative trends in late spring and summer, but statistically significant values are observed only in August. At the same time, there are positive trends in September and October, some of which are statistically significant. This means that the trend of increasing water shortage in August is quickly overcomed by the trend of increasing water surplus in the next two months.

Table 4.

*Trends (per decade) in precipitation-evaporation difference (in mm) in the model karst regions in the period 1979–2018. Statistically significant trends (at p <0.05, where **p** is significance) are bolded*

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Devetashko Plateau	0.1	0.1	0.1	-0.2	-0.2	-0.1	0	**-0.4**	0.3	**0.3**	-0.2	0.1	0
Brestnishka geosystem	0.2	0.1	0.2	-0.1	-0.2	-0.1	0	**-0.4**	**0.4**	**0.3**	-0.2	0	0
Trigrad	0.1	0.1	0.3	-0.2	-0.2	0.2	-0.3	**-0.5**	**0.4**	0.3	-0.2	-0.1	0
Dabrash	0.2	0.2	0.3	-0.3	-0.2	0.1	-0.3	**-0.5**	0.3	0.2	-0.2	-0.1	0
Shumensko Plateau	0.2	0.1	0	-0.3	-0.1	-0.1	-0.2	-0.2	0.2	**0.2**	-0.2	0.1	0

Table 5.

*Trends (per decade) in sea level pressure (in hPa) in the model karst regions in the period 1979-2018. Statistically significant trends (at p <0.05, where **p** is significance) are bolded*

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Devetashko Plateau	-0.18	-0.82	-0.51	0.39	-0.19	0.04	**-0.41**	0.04	-0.34	-0.09	0	0.88	-0.1
Brestnishka geosystem	-0.19	-0.82	-0.47	0.41	-0.19	0.04	**-0.4**	0.05	-0.35	-0.08	-0.01	0.89	-0.09
Trigrad	-0.17	-0.76	-0.44	0.41	-0.2	0.07	-0.33	0.09	-0.39	-0.18	0.09	0.77	-0.09
Dabrash	-0.16	-0.7	-0.4	0.39	-0.2	0.05	**-0.34**	0.08	-0.4	-0.18	0.1	0.76	-0.08
Shumensko Plateau	-0.13	-0.79	-0.58	0.38	-0.21	0.08	-0.38	0	-0.38	-0.15	0.06	0.83	-0.11

Table 5 shows SLP trends in the five model karst regions in the period 1979–2018. There are negative trends in average annual values, but they are not statistically significant. The most of the monthly trends are also negative, but only July trends are statistically significant and not in all five regions. Positive trends exist in April, June, August, November and December, but they are not statistically significant. Overall, it can be summarized that, despite the different trends, SLP in the studied model karst regions does not show significant changes over the period 1979–2018, except for July.

CONCLUSION

The climate of the five model karst regions is largely dependent on their location, especially on their altitude. The three relatively low-lying regions in northern Bulgaria are characterized by higher air temperatures, moderate precipitation and higher evaporation. In general, this results in a longer period of negative values (water shortage) of precipitation-evaporation difference, which lasts approximately half a year. Accordingly, the average annual values of this difference are slightly above zero, which still leaves these regions with small water surplus. The two southern and higher regions in the Rhodopi mountains have lower air temperatures, higher precipitation, lower evaporation and respectively higher values of the difference precipitation-evaporation. This makes them water sources in three quarters of the year. The average annual values of this difference are significantly higher than those of the other three regions in northern Bulgaria. The SLP has a similar intra-annual course in the five model karst regions. In terms of trends, there is a widespread rise in air temperatures mainly during the months of the warm half-year. There is also a significant increase in average annual air temperatures. Since air temperature is essential for evaporation, the trends in evaporation are similar to those in air temperatures. Precipitation, which depends mainly on atmospheric circulation, shows different trends in the different months. The precipitation increases mainly in September and October, and decreases in August. Average annual values do not show significant tendencies. Precipitation-evaporation difference follows precipitation trends as evaporation trends are one order of magnitude lower. No significant changes are observed in SLP.

Revealed trends have different effect on the processes in karst regions. Air temperature rise should accelerate these processes. On the other hand, this increase is observed in months when there is a decrease in precipitation and respectively of residual water in the studied regions. Lower precipitation should slow down karst processes. At the same time, precipitation rise in September and October is not associated with a significant increase in air temperatures. However, there is some increase in air temperatures in these months, which leads to a conclusion that the processes in the model karst regions should intensify. No definite conclusion can be drawn for the summer months. Looking at the trends in average annual values, where there is a significant increase in air temperature and no trends in precipitation, it can be concluded that the processes in karst regions should generally increase their intensity. This conclusion could be confirmed or rejected by a future research, where relevant data from karst systems/caves will be included.

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