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CHARACTERIZATION OF THE KARST WATER REGIME IN THE DANUBE CATCHMENT AREA (BULGARIA)

Abstract: The purpose of study is to estimate the role of karst springs in the formation of the flow of the Bulgarian rivers that are right tributaries of the Danube River. The study area includes the region from the Danube River to the main ridge of the Balkan (Stara Planina), representing a major water divide that separates the Black Sea catchment area from the Aegean one. The eastern border represents the watershed between the Danube and the Black Sea hydrological zones. From a geological point of view, the northern part of the area is located on the Moesian platform and the southern part belongs to the Fore Balkan and Balkan areas where various types of rocks of different geologic age outcrop. In some of them, there are conditions for the formation of karst water. In the northern part of the area they form distinct aquifers that gradually sink to the north; this is so called "platform" type of karst. In the southern mountainous part there are numerous karst basins. The most significant of karst springs are included in the national groundwater monitoring network. The hydrographs of karst springs are analyzed in view of the specific features of karstification. To classify the studied springs with respect to their regime, several indicators are used. Furthermore, the role of karst waters in the river runoff of the Bulgarian tributaries of the Danube River is assessed.

Key words: karst, karst water, hydrological regime of karst springs

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Introduction

Groundwaters have an important role in the formation of the river flow. Its contribution is largely dependent on various natural factors. In Bulgaria, due to various physical-geographical, geological and tectonic conditions, different types of groundwater are presented. Widespread karst water is linked both to clearly formed artesian aquifers and mountain karst basins with networks of cavities and galleries. Many karst springs are included in the national monitoring network. The purpose of this study is to summarize the data from the flow regime of the karst springs in the Bulgarian Danube catchment and to assess their role in the formation of the river flow. The results allow us to compare some of the indicators characterizing the regime of springs with view of considering the conditions for the formation of karst waters.

The object of the study is to characterize the main features of the regime of karst springs located in the drainage area of the Danube River. We have chosen 44 karst springs that are included in the National Hydrogeological Network. The study period is 1981-2012. The observation period includes wet, dry, and normal years.

Characteristics of the Studied Area

The study area is the largest area of water management in Bulgaria with a total area of 47,000 km^2 (Fig. 1). It includes the catchment areas of all Bulgarian tributaries of the Danube River. With the exception of the Iskar River, the headwater sources of almost all tributaries are on the ridges and the northern slopes of Stara Planina. Stara Planina (Balkan) is a mountain range with an average altitude of about 900 m and its highest peaks reach over 2,000 m above sea level. The mountain orientation is from the west to the east and divides Bulgaria into two parts: Northern and Southern. The rivers Lom, Ogosta, Vit, and Yantra are the main river courses from the west to the east that collect water from the ridges of the Balkan Mountain. The Danube tributaries originating from the lower parts of the northern slopes and the foothills are with smaller catchments – these are the rivers Topolovets, Voinishka, Vidbol, Archar, Skomlya, Tsibritsa, Skat, and Rusenski Lom. All Bulgarian tributaries of the Danube River flow northward through the Fore-Balkan area and enter the Danubian Plain. Only the Iskar River has its headwater source in Southern Bulgaria, in the highest mountain on the Balkan Peninsula – Rila, and crosses the Balkan Mountains forming a deep gorge before entering the Danube Plain. The water stage of the Danube River, which is draining the study area, is generally between 35 and 10 m. Digital elevation model for the study area and the catchment characteristics at the river gauge stations are found in the paper by Orehova & Vasileva (2014).

The climatic conditions are important for the formation of surface runoff. The largest part of the drainage area is characterized by temperate climate, and only in the higher parts of the Balkan Mountains the climate is typically mountainous. The mean annual rainfall varies from 400-500 mm to more than 1200-1300 mm, and the average annual air temperature is in the range 10-12°C in the plain part of the study area.

Geological and tectonic conditions are important for the groundwater formation. Different rocks in terms of composition, age, and genesis are largely spread over the area, which determines the availability of different types of groundwater. The conditions of their occurrence are defined especially by the tectonic features. A greater proportion of the area is located within the Moesian platform. It is part of a larger platform structure located in the lower reaches of the Danube River that extends to the northern slopes of the Balkan Mountains and represents a typical artesian basin. It separates several arranged floors of aquifers. In the central and southern part of the artesian basin, as a result of regional faults in the east-west direction, the position of aquifers is block complicated. The southern part of the area, located within the main Balkan Mountains range, is a formed hydrogeological massif of fissure waters in weathering and tectonic cracked zones and drained karst mountain basins, mainly found in the Triassic, Upper Jurassic-Lower Cretaceous carbonate rocks. Karst waters are also widespread within the artesian basin (Antonov & Danchev, 1980). They are attached to the Sarmatian, Upper Cretaceous, Upper Jurassic-Lower Cretaceous aquifers. For the most part they are confined, with the exception of the outcrops in the peripheral parts of the basin where the aquifers are recharged. There are outcrops of karsting carbonate rocks, especially in the southern parts of the artesian basin, which are partially or completely elevated above local erosion basis and can also be treated as separate karst basins (Boyadjiev, 1964; Antonov & Danchev, 1980). Karst basins in the mountain areas and the artesian basins are recharged through rainwater but some of them also receive additional recharge from surface waters. They are drained by springs of different character depending on the specific conditions. These springs are important for the water supply in the surrounding settlements. The most important karst springs that are associated with highly-karstified areas are included in the National Monitoring Network. This entails regular measurements of the flow rates and the temperatures at the observed groundwater monitoring points. Some of these springs have been the subject of earlier studies (Boteva & Raykova, 1968, 1970; Spasov, 1998; Benderev et al., 2014) and their research is taken into consideration.

The National Monitoring Network was established in 1958 and aims to clarify the regime of groundwater in different regions of the country that are characterized by specific hydrological conditions and geological setting (Betsinski, 1958). The data from the observations are published in hydrogeological yearbooks, reference books and are used in different hydrogeological studies and analyses (Orehova & Roussev, 2004). Currently the network includes 446 springs, dug wells, boreholes and artesian wells.

Data Base and Methods

The data of the study includes the spring discharge values for 44 karst springs (Fig. 1) from the National Hydrogeological Network for the period 1981-2012. Two thirds of the springs are measured on a monthly basis, while the other one third is measure on a daily basis (Tab. 1). The chosen observation period covers a variety of years in terms of humidity – wet, normal, and dry. Furthermore, there is a full time-series of spring discharge values for it. The methods include the analysis of the karst spring hydrographs and the processing of data on the discharge.

To achieve the goal of this study, some in the water flow regime and its significance for the flow formation of the tributaries of the Danube River are initially established. To elucidate the regime of springs, hydrographs that show the changes in their water flows were drawn. Some of the basic statistical characteristics of the springs are determined – average, maximum and minimum discharges, median, standard deviation, coefficient of variation. The analysis of the results uses indicators characterizing the change of water amounts of springs.

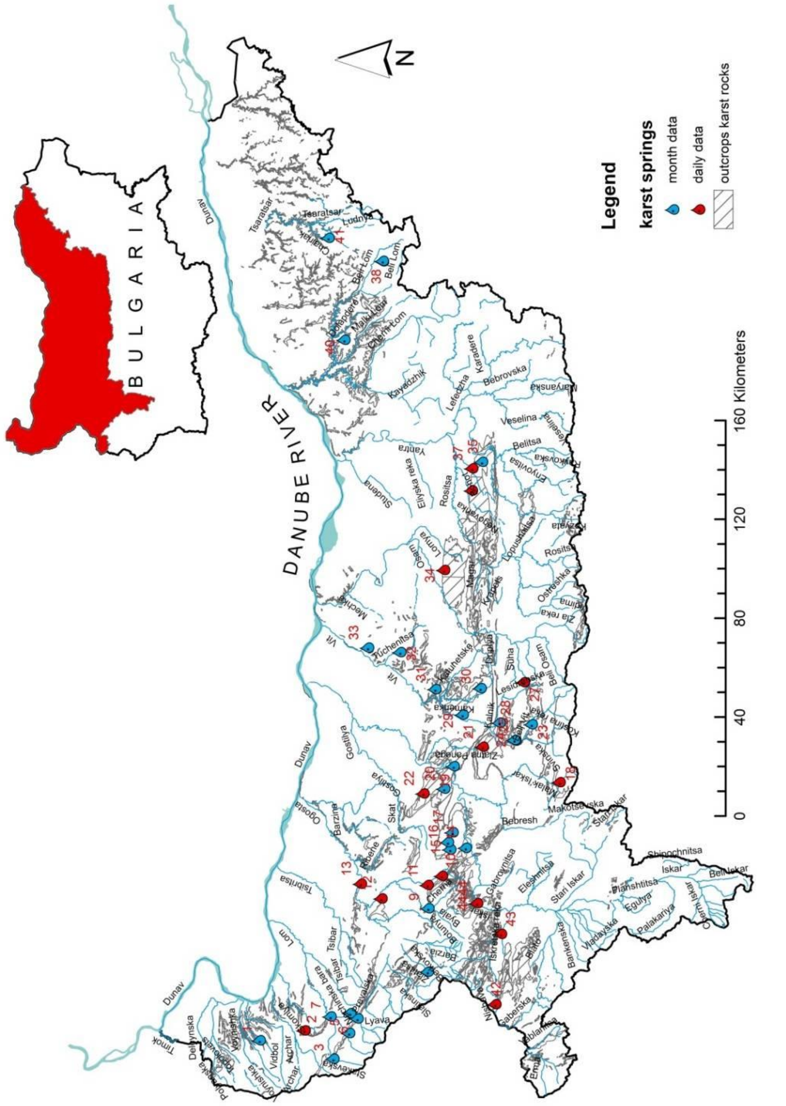

Fig. 1. Outcrops of carbonate rocks and studied karst springs in the Danube hydrological zone of Bulgaria (The numbering of sources is in Tab. 1)

Tab. 1. Characteristics of the monitored karst springs

№	River Basin	Spring Name	Karst Basin	Observation period, years	Frequency
1	Vidbol	Gramada	Neogene aquifer	32	12
2	Archar	"Vreloto"- Bela	N. Belogradchik anticline	32	365
3	Lom	"Vreloto", Krachimir	Salash syncline	31	12
4	Lom	"Selskiya kladenec", Targovishte	Salash syncline	30	12
5	Lom	"Selskiya kladenec", Targovishte	Salash syncline	30	12
6	Lom	"Vodni pech", D.Lom	Salash syncline	32	12
7	Lom	"Vreloto", Ruzinci	N. Belogradchik anticline	32	12
8	Ogosta	"Barkotccitsa", Chereshovitza	Western part of Berkovitsa anticlinorium	32	12
9	Ogosta	Stoyanovo	Bistrets-Matnitsa	32	12
10	Ogosta	Bistrets	Bistrets-Matnitsa	32	365
11	Ogosta	Beli izvor	Bistrets-Matnitsa	32	365
12	Ogosta	Pali lula	Plateau "Pastrina"	32	365
13	Ogosta	Kobilyak	Vladimirovo	32	365
14	Iskar	Moravitza	Mezdra syncline	32	12
15	Iskar	Krapetz	Mezdra syncline	28	12
16	Iskar	"Selska cheshma", Varbeshnitza	Mezdra syncline	31	12
17	Iskar	"Ezeroto", Gorna Kremena	Mezdra syncline	31	12
18	Iskar	"Sveta Troitza", Etropole	Etropole syncline	32	365
19	Iskar	Karlukovo	Lukovit syncline	32	12
20	Iskar	"Dragievo ezero" , Kameno pole	Kameno pole syncline	31	12
21	Iskar	"Glava panega", Zlatna panega	Zlatna Panega	32	365
22	Iskar	"Ezeroto", Gabare	Kameno pole syncline	27	365
23	Iskar	"Peshta", Iskretz	Iskretz	32	365
24	Iskar	"Zhitelyub", Lakatnik	Milanovo syncline	32	365
25	Vit	"Kliuch", Teteven	Teteven anticline	24	12
26	Vit	"Goliama vidra", Glojene	Teteven anticline	26	12
27	Vit	"Malka vidra", Glojene	Teteven anticline	30	12
28	Vit	"Toplia", Goliama Jeliazna	Teteven anticline	32	365
29	Vit	Golyama Jeliazna	Teteven anticline	32	365
30	Vit	"Goliam izvor", Bulgarski izvor	Zlatna Panega	31	12

№	River Basin	Spring Name	Karst Basin	Observation period, years	Frequency
31	Vit	"Batovo ezero", Dermantzi	Lukovit anticline	31	12
32	Vit	"Baliovo ezero", Ugarchin	Lukovit anticline	28	12
33	Vit	"Selski dol", Barkach	Lom-Pleven depression	28	12
34	Vit	"Bakalia", Pleven	Lom-Pleven depression	31	12
35	Vit	"Ezero", Riben	Lom-Pleven depression	28	12
36	Osam	"Maarata", Krushuna	Lovetch-Tarnovo	32	365
37	Yantra	"Glavata", Beliakovetz	Lovetch-Tarnovo	32	12
38	Yantra	"Peshterata", Musina	Lovetch-Tarnovo	32	365
39	Yantra	"Bohot", Hotnitza	Lovetch-Tarnovo	29	365
40	Rusenski lom	"Poroishte", Poroishte	Baremian-Aptian aquifer	28	12
41	Rusenski lom	"Poroishte", Poroishte	Baremian-Aptian aquifer	28	12
42	Rusenski lom	"Varovichetz", Pisanetz	Baremian-Aptian aquifer	31	12
43	Chairlak	"Voden"	Baremian-Aptian aquifer	32	12
44	Nishava	"Vreloto", Berende izvor	Nishava	32	365

The obtained results are used to determine the maximum, the minimum, and the average flows. They are distributed according to the stability of the water regime. One of the oldest numerical indicators used is the indicator of Ovchinnikov (1955) representing the ratio Q_{max}/Q_{min}, in which the springs are divided into 5 categories. An assessment according to Gigineyshvili (1979) is also made – it represents the annual internal oscillation of the flow of karst springs (C_v %) showed by the standard deviation of the monthly average from the average annual flow. The indicator of Panayotov (1983) is also used – it characterizes the center of internal annual distribution of runoff (σ) and represents the standard deviation from its centers in different hydrological years. The similarities and differences of the regimes of the observed karst springs are explored. The role of karst springs in the flow formation in the Bulgarian tributaries is assessed.

Results and Discussion

The analysis of the prepared spring hydrographs confirms the impact of major natural factors on the water discharge volumes. Different types of hydrographs are identified according to the nature of karstification, recharge, and the climatic conditions. Overall, the most significant dynamics in the change of flow rates is observed in the karst springs located in the highest southern part of the observation area, which is dominated by areas with typical Alpine Karst where the rainfall passes quickly through the unsaturated zone and reaches the springs, e.g. the Zhitelyub spring (number 24 in Tab. 1) (Fig. 2).

Relatively more stable flow rates are observed in the springs in areas with a substantial saturated zone and with permanent additional river recharge, e.g. Kobilyak spring (number 13 in Tab. 1) (Fig. 3).

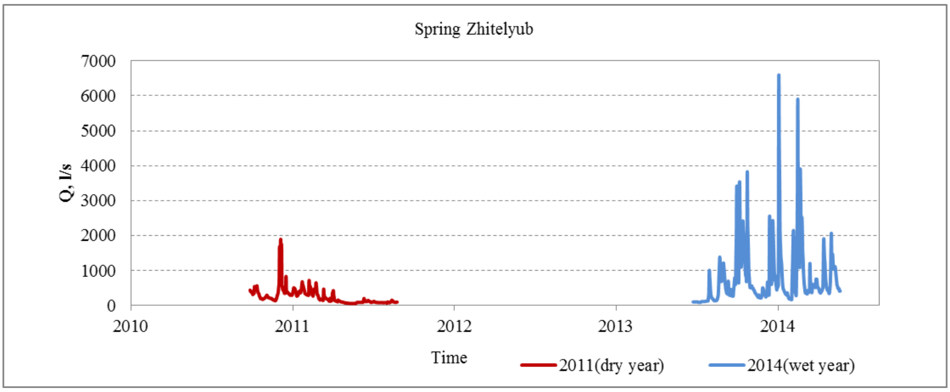

Fig. 2. Change in the water amount of the Zhitelyub spring in a dry and a wet year

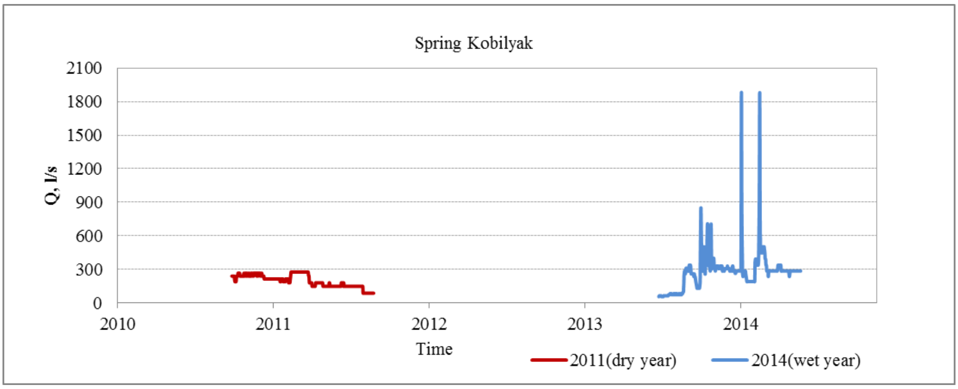

Fig. 3. Change in the water amount of the Kobilyak spring in a dry and a wet year

Analyzing the effects of precipitation for the period of observation, we found that the maximum discharge values are associated with snowmelt and the spring high flow (Fig. 4). The presence of snowmelt combined with rainfall suggests that the high volume of water and the peaks in the flow rates of springs are mainly in April before the peaks of rainfall in May - June (Fig. 4 – Iskretz (number 23 in Tab. 1)). In some of the springs, the maximum flow rates cover a relatively long timespan, which depends on the particular recharge conditions, including periods before (Fig. 4 – Bistrets (number 10)) or after the month April (Fig. 4 – Goliama Jeliazna (number 29)). The springs with the highest variation are the ones for which an important role have river recharges (Fig. 4 – Zlatna Panega (number 21)).

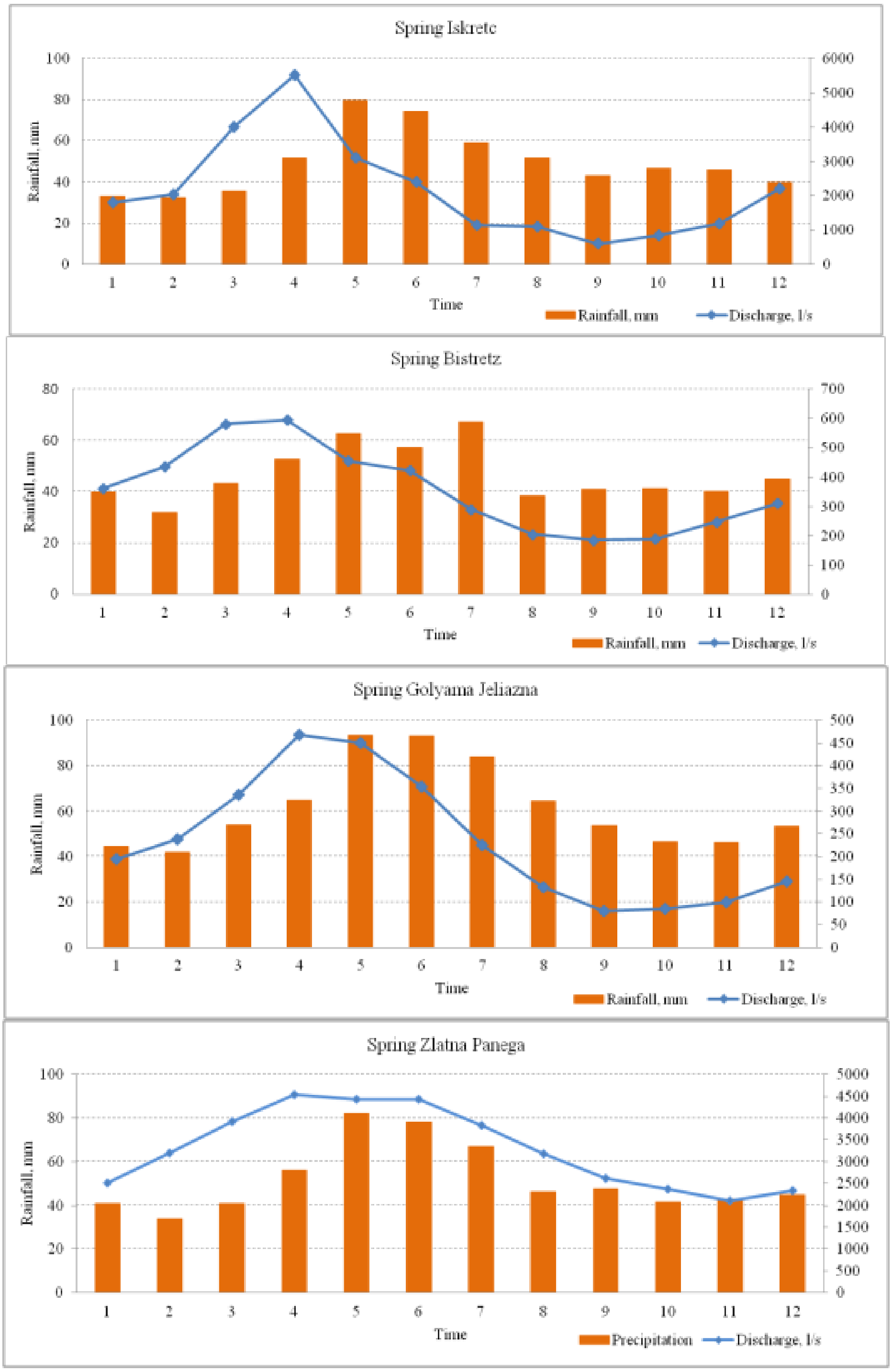

Fig. 4. Monthly average values of rainfall and water quantities of selected springs

To characterize the changes in the discharge values of the springs, we assessed them by several indicators and the relevant classifications for them (Tab. 2).

Tab. 2. Indicators' characterizing the flow regime of the monitored karst springs (The colors are taken from Fig. 5-7)

№	Spring name	Q_{min}, l/s	Q_{max}, l/s	Q_{max}/Q_{min} Ovchinnikov	C_v, % Gigeyneshvili	σ, Panayotov
1	Gramada	2.2	71.5	32.5	71	0.25
2	"Vreloto"- Bela	1	538	538	52	0.51
3	"Vreloto", Krachimir	9	1,316	146.2	121	0.48
4	"Selskiya kladenec", Targovishte	10	234	23.4	21	0.51
5	"Selskiya kladenec", Targovishte	0.2	75	375	54	1.33
6	"Vodni pech", Dolni Lom	5	702	140.4	38	0.96
7	"Vreloto", Ruzinci	1.18	75	63.6	40	1.54
8	"Barkotccitsa"	4.5	32.5	7.2	22	0.12
9	Stoyanovo	2	949	474.5	26	0.43
10	Bistrets	2	4,142	2,071	35	0.38
11	Beli izvor	0	1,450	∞	46	0.60
12	Pali lula	8	2,465	308.1	25	0.58
13	Kobiliak	48	1,677	34.9	32	0.30
14	Moravitza	0.17	49.6	291.8	61	0.84
15	Krapetz	30	650	21.7	42	0.68
16	"Selska cheshma", Varbeshnitza	0.8	36	45	38	0.58
17	"Ezeroto", Gorna Kremena	1.7	437	257.1	90	0.90
18	"Sveta Troitza", Etropole	0	574	∞	47	0.92
19	Karlukovo	2.4	116	47.9	27	0.32
20	"Dragievo ezero" , Kameno pole	15.7	736	46.9	58	0.47
21	"Glava panega", Zlatna panega	780	27,000	34.6	18	0.49
22	"Ezeroto", Gabare	1	1,489	1,489	61	0.62
23	"Peshta", Iskretz	6	35,000	5,833	58	0.73

№	Spring name	Q_{min}, l/s	Q_{max}, l/s	Q_{max}/Q_{min} Ovchinnikov	C_v, % Gigeyneshvili	σ, Panayotov
24	"Zhitelyub", Lakatnik	11	16,600	1,509	39	0.81
25	"Kliuch", Teteven	0.12	13	108.3	63	0.26
26	"Goliama vidra", Glojene	45	178	4	14	0.10
27	"Malka vidra", Glojene	0.8	50	62.5	59	0.25
28	"Toplia", Goliama Jeliazna	0	11,070	∞	54	0.59
29	Karst spring, Goliama Jeliazna	0	2,400	∞	39	0.68
30	"Goliam izvor", Bulgarski izvor	36	524	14.6	40	0.45
31	"Batovo ezero", Dermantzi	1	311	311	66	0.44
32	"Baliovo ezero", Ugarchin	1	40	40	43	0.73
33	"Selski dol", Barkach	3.1	40	12.9	24	0.58
34	"Bakalia", Pleven	1	7	7	28	0.32
35	"Ezero", Riben	4	136	34	74	0.52
36	"Maarata", Krushuna	3	9,300	3,100	83	0.67
37	"Glavata", Beliakovetz	2.3	327	142.2	55	0.43
38	"Peshterata", Musina	25	10,000	400	68	0.46
39	"Bohot", Hotnitza	1	12,700	12,700	70	0.46
40	"Poroishte"	0.19	9.17	48.3	37	0.56
41	"Poroishte"	0.09	4.76	52.9	55	0.46
42	"Varovichetz", Pisanetz	17.5	38	2.2	16	0.04
43	"Voden"	30	172	5.7	36	0.18
44	"Vreloto", Berende izvor	4	1,838	459.5	50	0.74

The ranges of variation in the flow rates of the studied springs differ substantially in accordance with the specific conditions for karstification, the recharge and the movement of water. The flow of some of the springs is interrupted during dry seasons. After comparing the maximum and the minimum water flows as represented by the indicator of Ovchinnikov (1953), all observed springs are characterized by high variability in varying degrees (Fig. 5) with values from 2.2 to infinity.

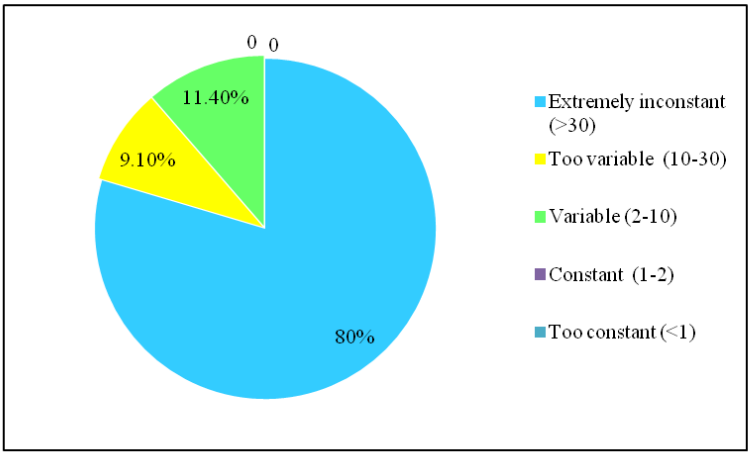

Fig. 5. Distribution of springs according to the indicator of Ovchinnikov (1953)

The indicator of Gigineyshvili (1979) gives a better idea of the nature of the inter-annual variation of water rates of the springs (Fig. 6). It represents the relative standard deviation of the average monthly water discharge from the average annual flow. Even better results are obtained when comparing this indicator for a particular spring with a Standard River in the same area. According to this indication, in the observed area there are predominantly springs with preserved zonal character and as a result, the regime of the respective spring is largely similar to the regime of the river flow in the area. Only one spring is characterized by not sustainable regime. A stable regime is observed in the karst springs that are draining the pronounced aquifers in the northern part of the region and springs from the karst mountain basins in which there are a substantial saturated zone or an important role is played by constantly recharging rivers.

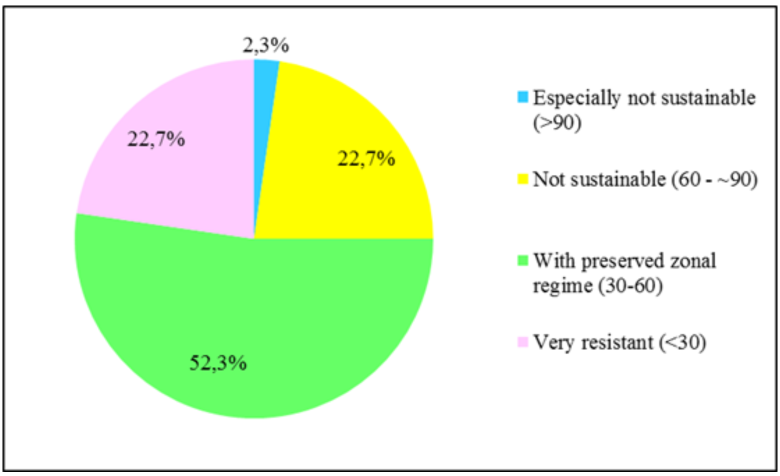

Fig. 6. Distribution of springs according to the indicator of Gigineyshvili (1979)

The indicator of Panayotov characterizes the intra-annual distribution of the flow of karst springs (Fig. 7). Most of the studied springs are with average resistant intra-annual distribution. To a large extent, there is an overlap of the springs that belong to the resistant group. What is more, there is a considerable overlap between the type of springs that fall into the group of very constant springs according to the indicator of Panayotov and those classified as very resistant according to the indicator of Gigineyshvili. The group with highly variable flow comprises mainly of springs that are draining typical karst mountain basins and have a well-developed channel-gallery network. Regardless of the existence of certain repetitions, there is no correlation between the two indicators (Fig. 8). However, there is a slight tendency for the increase of the values in one indicator to result in the increase of the values in the other. Probably a closer relationship could be established if the springs are divided into different groups depending on the type of karst.

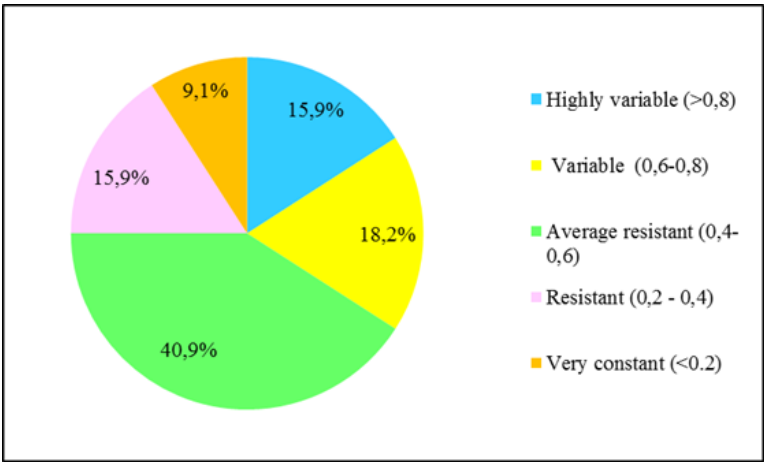

Fig. 7. Distribution of the springs according to the indicator of Panayotov (1983)

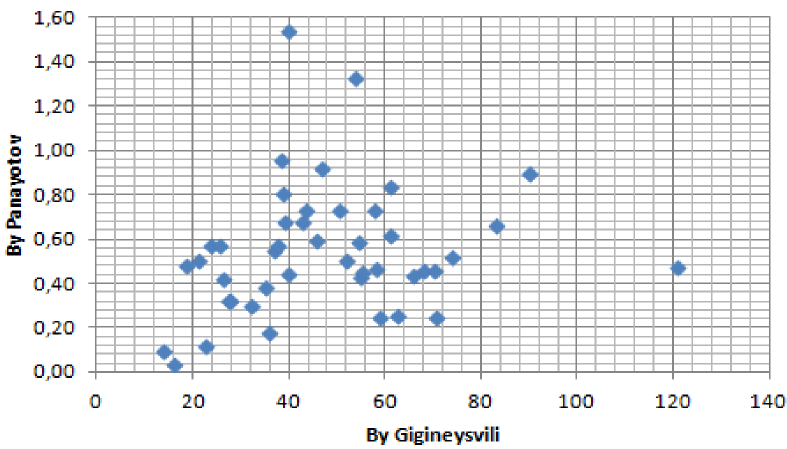

Fig. 8. Correlation between the indicators of Gigineyshvili and Panayotov

The discharge of the studied karst springs is part of the runoff of the respective tributary of the Danube River. The groundwater flow formed by them for the period 2009-2015 is 11,217 l/s (11.2 m^3/s) or only 6.59% of the total flow towards the Danube River for the same period (the used data is from the NIMH hydrological network stations for quantitative monitoring of surface waters located at the mouths of rivers). Their role is different for individual rivers according the involvement of rocks and nature of karstification (Tab. 3).

Tab. 3. Ratio between the groundwater flow and surface water flows

River	Hydrological station, №	Total flow, l/s	Groundwat. flow, l/s	Groundwat. flow / Total flow, %	Observ. period, years
Voynishka	12,850	965	8.2	0.9	2009-2015
Lom	14,840	7,213	528.0	7.3	2009-2015
Ogosta	16,850	24,993	1,208	4.8	2009-2015
Iskar	18,850	42,733	6,834	16.0	2009-2015
Vit	21,800	12,694	1,396	11.0	2009-2015
Osam	22,800	11,929	183	1.5	2009-2015
Yantra	23,850	62,574	1,026	1.6	2009-2015
Rusenski Lom	31,380	7,096	33.4	0.5	2009-2015

Even though the National Network includes most of the major karst springs in Bulgaria, the available values do not characterize the amount of karst water involved in the formation of the total river flow. It is quite probable that the role of karst waters in the river runoff is more prominent, especially for the rivers Iskar, Vit and Osam. Here the karst is widespread. These rivers basins there are many other karst springs which are not included in the monitoring network.

Conclusion

Karst springs are characterized by well-expressed seasonality of their discharge. In this study, the flow regime of the major karst springs from the Danube hydrological zone is analyzed based on several indicators (Ovchinnikov, Gigineyshvili and Panayotov). The data are from the National Hydrogeological Network, and the reference period is 1981-2012. The springs are classified according to degree of their variability and therefore their resistivity to droughts. Our results somewhere confirm results to previous authors, but show very clear and in details real changes in the regime of the springs. Ovchinnikov indicator gives a very rough assessment. We think it is better to use both parameters by Panayotov and Gigineyshvili.

Furthermore, the role of karst waters in the river runoff of the Bulgarian tributaries of the Danube River is assessed. For the period 2009-2015 the total discharge of the major karst springs is about 6.6% from the total river flow of the Danubian tributaries.

This value varies for different Bulgarian rivers and is maximal for the Iskar River (16%). The most significant is the role of the observed karst springs in the watershed of the river Iskar. It is shown in Tab. 3. If we use the springs which are not included in the National Monitoring Network, whose average flow rate is about 1,500-2,000 l/s, this ratio will be higher about 20%. This demonstrates the essential role of the karst water for the formation of runoff, although the area of outcrops of karst rocks in the watershed is fewer than 12%. These rocks are basically in the middle reaches of the river where it crosses the Stara Planina and Fore and they formed a mountain karst. The variability of spring flows is related mainly to the degree of karstification of limestone or marbles and specific features of the recharge of karst basins. The amount and temporal distribution of the precipitation and snowmelt according with the amount of additional recharge from surface water are important in this respect. The same conclusion was obtained and in the part of Stara planina belonging to Serbia (Đurović & Živković, 2013).

The preliminary conclusions concerning the karst springs presented here are the beginning of an in-depth study of their regime and specific features. Further statistical processing of the data base about the flow rates and their relations to various factors could help in solving a number of problems related to both the water management and clarification of the basic principles for the formation of the flow of these springs in relation to the impact of natural and anthropogenic factors, including climate issues.

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КАРАКТЕРИЗАЦИЈА ВОДНИХ РЕЖИМА У КРАСУ У СЛИВУ РЕКЕ ДУНАВ (БУГАРСКА)

Резиме: Основни циљ рада је процена улоге крашких извора у формирању протицаја река, десних притока Дунава на територији Бугарске. Поље истраживања укључује регион који се простире од реке Дунав на северу до главног гребена Балкана (Старе планине), која представља развође између Црноморског и Егејског слива на југу. Источну границу представља вододелница између Дунавске и Црноморске хидролошке зоне. Са геолошког становишта, северни део ове области се налази на мезијској платформи, док јужни део припада балканским структурама, где постоје стене различите старости. У некима од њих постоје услови за формирање крашких извора. За класификацију истраживаних извора, у погледу њиховог режима, коришћени су различити индикатори, па су они класификовани према степену њихове варијабилности и отпорности на сушу. Коришћени су подаци Националне Хидрогеолошке мреже за временски период 1981-2012. На крају је извршена процена удела крашких вода у формирању протицаја река. Удео крашких извора у формирању укупног протицаја притока Дунава, у просеку износи 6,6%, за период 2009-2015, са максималном вредношћу од 16% за реку Искар.

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