Estimation of Groundwater Resources in Bulgarian Mountain Areas From Stream Baseflow

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Abstract

Mountains in Bulgaria are important areas for generation of the freshwater resources of high quality. High precipitation sums in combination with low evapotranspiration provide large runoff values. These resources, however, are rather vulnerable to droughts, as was registered during last decades. The aim of the study is to evaluate stream baseflow as a measure of the groundwater resources in a study area, along with its temporal variability. Numerous hydrometric stations provide precious information on the water resources in the area. The method of baseflow separation was used in several modifications including the method of local minimum and the Bflow program. For the purpose of the study, stream gauge stations were chosen with the catchment area between 50 and 1000 km^2. Daily data on stream runoff were used for the period of 2000-2005. The obtained results of the baseflow index correspond to values typical for sub-humid climate. Larger values are obtained for watersheds with carbonate terrains. Temporal variability of the baseflow is important in respect to climate variability. The partitioning between quick and baseflow is also variable through years. The baseflow separation is the simplest method for the groundwater resources evaluation in mountain areas.

Keywords: *baseflow; groundwater resources; stream runoff.*

Introduction

It is known that groundwater and surface water are a single resource (1). Time series of a stream hydrograph clearly show that both quickflow and baseflow components are present. Baseflow is the groundwater contribution to streamflow. It sustains river runoff during periods without precipitation and snowmelting. Baseflow is estimated through hydrograph analysis by separating streamflow into surface runoff and baseflow. Input data are time series of daily streamflow data. The baseflow index (BFI) is the ratio of mean annual baseflow to mean annual flow.

Mountain watersheds are usually scarce in groundwater data. The largest groundwater body in the Central Balkan is used as an object for the current research. The aim of the study is to evaluate stream baseflow as a measure of the groundwater resources in the study area. For this purpose, two methods are selected - it is always recommended to separate the baseflow with more than one method.

Study area

The study refers to the groundwater body "Karst and fissured groundwater in the Central Balkan" with total area of 8,904 km^2 that belongs to the Danube hydrological zone (Fig. 1). This is a mountain area with altitude up to 2,376 m (Botev Peak). The time-series at the river gauge stations located in this territory are used in the study.

The climate of the study area is temperate. The rainfall varies from about 700 mm yearly at the foothills up to more than 1000 mm in the high Balkan mountain (2). Seasonality is well expressed. The area is predominantly rural. The Central Balkan National Park (716.7 km^2) covers the highest part of the study area. The park includes 9 nature reserves. The general landscape types are the high-mountain treeless zone, the temperate humid mountain forests and the landscape of the Balkan mountain karst.

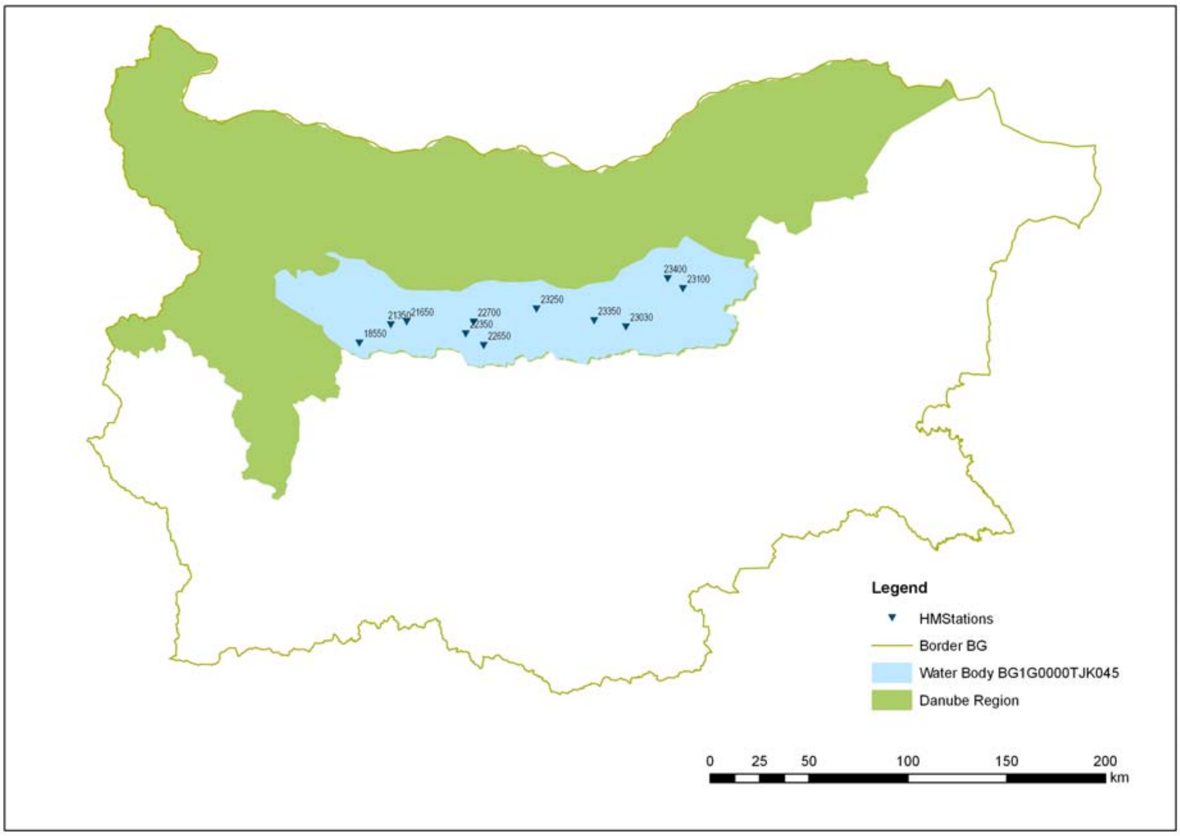

Fig. 1. The location of the study area and the used river gauge stations.

The main rivers in the Danube hydrological zone are tributaries of the Danube River: Ogosta, Iskar, Vit, Osam (3), Yantra and Rusenski Lom. The maximum monthly discharge values are typical for spring months from March to May. The minimum monthly discharge values occur from August up to October.

From tectonic point of view, North Bulgaria belongs to the Moesian platform and the Balkan zone (4). The Moesian platform is composed of up to 4-5 km thick Mesozoic deposits buried beneath Palaeogene, Neogene and Quaternary sediments. The Central Balkan unit is built mainly from continental and shallow marine clastic and carbonate rocks of Mesozoic age. The groundwater is related to fissured and karstified formations and is drained by the river network. The most important for water supply are numerous karst basins drained by springs.

The mountain areas in Bulgaria are with scarce information concerning groundwater. Commonly available data are spring discharges. Available river gauge stations are useful for estimating the total freshwater resources.

Method and data

Numerous baseflow separation techniques are known, both graphical and analytical using recursive digital filters. Different methods are: fixed interval, sliding interval, and local minimum methods. Recent reviews of the baseflow analyzes were made by Tallaksen (5), Smakhtin (6) and many others. In this study, two techniques are used to separate baseflow for the study area: graphic filter Bflow and BFI+ model. The filter Bflow estimates baseflow from streamflow records using the methodology outlined by J.G. Arnold and co-authors (7-8) The filter is passed over the stream flow data 3 times (forward, backward, and forward), and the result is presented by Pass 3. The BFI+ model was used as alternative method (9). The model based on the local minimum method was chosen with standard parameters N=5, f=0.9. Both techniques perform a separation of the baseflow from the total streamflow and calculate the baseflow index.

For the purpose of the study, daily time-series at river gauge stations from hydrological network are used. The hydrological network is in operation at the National Institute of Meteorology and Hydrology at Bulgarian Academy of Sciences (NIMH-BAS). In our study we evaluated river stations in the upper part of the selected watersheds. Due to this, we could consider river discharges to be near to natural river flow conditions. The period 2000-2005 is investigated. The data are provided in the frames of the JICA report (10). The baseflow volume for each year is evaluated along with the base flow index BFI. The Bflow program is used for time-series starting from 1 September, as required.

Amongst many river gauge stations within the study area, we chose only these with drainage area in the interval 50-1000 km^2, unaffected by dams and reservoirs, according to recommendation of C. Santhi (11). It is assumed that the groundwater divide do not differ from the superficial catchment area.

Results and discussion

The study area covers the groundwater body BG1G0000TJK045 - “Karst and fissured groundwater in the Central Balkan” with total area of 8,904 km^2. The river gauge stations used for the study are listed in Table 1 along with the catchment characteristics including the area, average altitude and the altitude at the river gauge.

Table 1 Catchment characteristics at the studied river gauge stations.

N	River	Location	F, km2	Hav, m	H_o, m
18550	Malki Iskar	Etropole	54.3	1164	607.25
21350	Cherni Vit	Cherni Vit	159.2	1032	424
21650	Beli Vit	Teteven	306	1007	433.52
22350	Beli Osam	Troyan - kv.Vasilevska	187.3	1008	413.23
22650	Cherni Osam	Ch.Osam mah.Stoynovska	138.3	1338	553.01
22700	Osam	Troyan - kv.Velchovska	458.1	1034	353.1
23030	Belitsa	Vaglevtsi	199.5	597	299.72
23100	Lefedzha	Slivovitsa	740.5	522	89.59
23250	Vidima	Sevlievo - m.Chakala	556.8	659	203.86
23350	Dryanovska reka	Tsareva livada	163.6	667	315.2
23400	Dzhulyunitsa	Dzhulyunitsa	882	482	62.02

Daily discharges at the chosen stream gauge stations are used as the input data. The period 2000-2005 is used for the baseflow separation by the BFI+ model, and for the Bflow program – since 1 September of 2000. Average baseflow characteristics obtained by the method BFI+ for the period 2000-2005 are presented in Table 2. The year 2005 was abundant in precipitation amount, and therefore the river runoff was much higher then usually. Therefore, the values for the shorter period 2000-2004 seem to be more representative.

Table 2 Average baseflow characteristics for the periods 2000-2005 and 2000-2004 (method BFI+).

N	2000-2005		2000-2004	
	Baseflow, mm	BFI [-]	Baseflow, mm	BFI [-]
18550	251	0.58	224	0.61
21350	337	0.56	283	0.62
21650	242	0.43	200	0.47
22350	249	0.45	202	0.5
22650	319	0.4	256	0.41
22700	204	0.43	159	0.43
23030	167	0.39	104	0.35
23100	88	0.33	76	0.37
23250	133	0.45	101	0.49
23350	172	0.49	142	0.52
23400	140	0.49	102	0.49

The method Bflow requires the time-series from the 1-st of September, and the results obtained for the respective hydrological years are presented in Table 3. The comparison between the two techniques shows that the values obtained by the BFI+ model give higher values for the baseflow volume and, therefore, for the baseflow index.

Table 3 Average baseflow characteristics for the period 1.09.2000-31.08.2004 (methods Bflow and BFI+)

N	Bflow		BFI+	
	Baseflow, mm	BFI [-]	Baseflow, mm	BFI [-]
18550	193	0.53	217	0.6
21350	251	0.57	278	0.63
22650	230	0.36	264	0.42
22700	140	0.39	159	0.44
23250	88	0.43	98	0.48
23350	128	0.46	141	0.51
23400	81	0.4	94	0.46

As an example, the baseflow and stream flow hydrographs for the gauge station N 22650 are presented in Figure 2. Large variability both of the baseflow and the BFI value for different years is evident.

The BFI+ model is a module of the software HydroOffice – it uses a local minimum method, with the standard filter: N= 5 and f=0.9. The original BFI program (12) used constant length of N-days period being equal to 5 days. The studies performed for Slovak catchments (13), however, showed that the utilization of a 5-days period gives overestimated values of the base flow in comparison with other methods often used in Slovak hydrogeological practice.

Different parameters are known to explain variations in BFI: topographic, soil, vegetational and climatic factors (11), but catchment lithology is considered as a primary factor in affecting baseflow and BFI (14). The lithological variations across the catchments are related to the associated variations in hydraulic and storage characteristics of those formations.

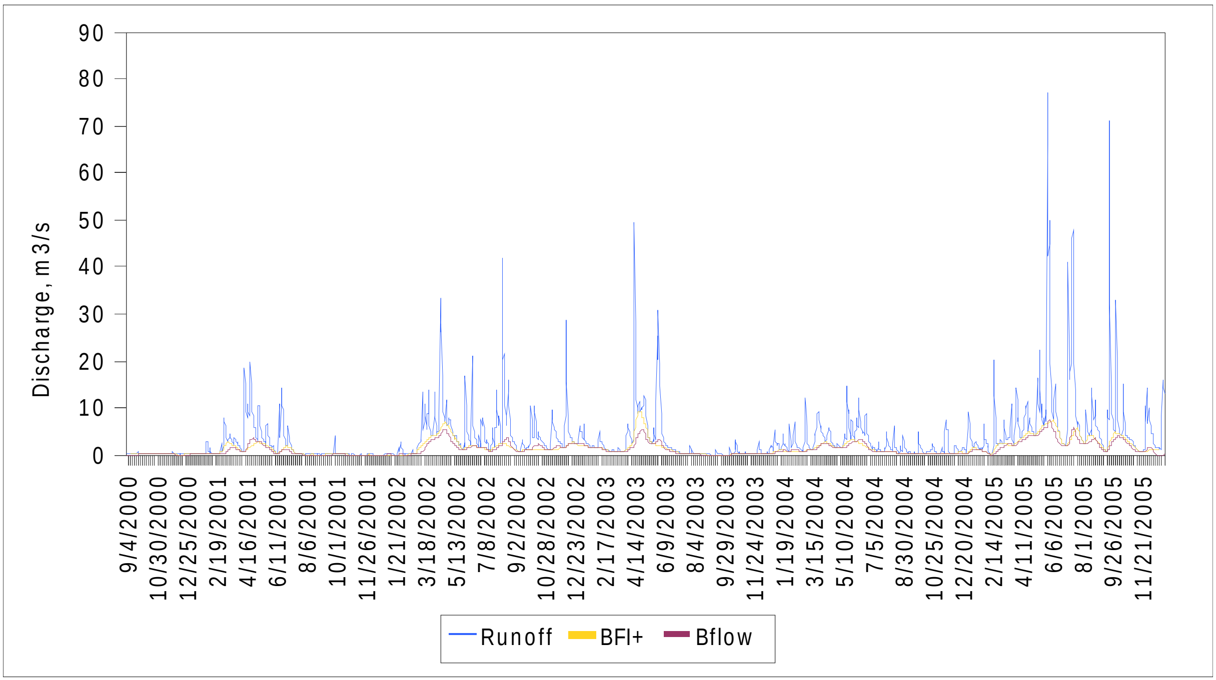

Figure 2. The baseflow and stream flow hydrographs at the gauge station N 22650.

The lowest values of the BFI are related to catchments with low permeable outcropping deposits of the J_2- K_1 age. Such are watersheds with river gauges NN 23030 and 23100. The outcropping Zlatarishka. Kamchijska and Gornonrjahovska Formation are built from terrigeneous deposits: sandstones, marls, siltstones. Higher values of the BFI are for watersheds with considerable areas covered by carbonate formations of the Jurassic and Triassic age. We plan to estimate the percentage of the area covered by high permeable formations within the catchment area. This value may be a predictor of the baseflow index BFI.

In general, the world-wide ratios of baseflow/precipitation and baseflow/river runoff are approximately 10% and 30%, respectively. These ratios show a high geographical variability, which is controlled by the regional climatic and hydrogeologic factors (15).

Conclusion

The stream flow consists from two components: surface runoff and baseflow. Baseflow is the groundwater contribution to the river runoff. Two baseflow separation techniques are applied for gauged river catchments that refer to the groundwater body BG1G0000TJK045 situated in the Central Balkan. The methods provide the baseflow volume and BFI averaged for the catchment areas.

The results derived for different years show large variability of the baseflow volume and baseflow index. In all cases results obtained by BFI+ give higher baseflow volume. Since the true values of the baseflow index are always unknown it is not possible to identify which of the methods provides the 'best' estimates of BFI (14). As it was stated by Slovakian authors (13), the use of BFI+ model with 5-days period overestimates the baseflow. Most likely, the Bflow method gives better estimate of the baseflow.

The BFI values obtained for the study area are of similar range as reported by Santhi et al. (11) for the conterminous USA for the humid regions. It is assumed that catchment lithology is the main factor that affects baseflow and BFI. In future we plan to define the relative share of the low permeable and high permeable formations within the catchment areas.

Acknowledgements

The authors gratefully acknowledge the use of the software BFI+ from the HydroOffice web site (http://www.hydrooffice.org/).

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