

Seasonal Variability of the Groundwater Regime for Several Aquifers in Bulgaria

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The purpose of the paper is to analyse the seasonal variability of the groundwater regime for several aquifers in Bulgaria. Stations from the National Hydrogeological Network were used. Observations of discharge for karstic springs and water level for wells were analysed. Time series for the 40-year period were processed.

The behaviour of the ratio $Q6M/q6m$ (runoff of the 6 wettest months over the 6 driest ones) for karstic springs was estimated. There was no significant correlation with the average value. All studied stations however showed high correlation ($r \sim 0.9$) between $Q6M$ and average discharge. This means that the recharge predetermines the average value of spring discharge. Similar results were obtained for water level in observational wells.

The seasonal pattern of the groundwater regime reflects the variations in the groundwater recharge that are related to the discharge of the 6 wettest months. This conclusion is the same for all studied aquifers: in Proterozoic marbles, Triassic limestones and dolomites, Cretaceous limestones, and proluvial-alluvial Quaternary sediments.

Introduction

The aim of this paper is to analyse the seasonal variability of the groundwater regime for several aquifers in Bulgaria. The variations of groundwater regime reflect the complex of conditions: region, geological age and lithological composition, altitude above sea level, climatic zone, type of the aquifer (porous, fissured, karstic), human impact, etc.

The basic territorial and hydrological units in Bulgaria are:

- Danube zone – drainage basin of all Bulgarian tributaries to the river Danube with temperate climate (European-Continental);
- Black sea zone - drainage basin of all Bulgarian tributaries with direct discharge to the Black sea with temperate climate and climate with Mediterranean influence south of the Stara Planina Mountain;
- Aegean zone - drainage basin of all South Bulgarian rivers with direct discharge to the Aegean Sea in the territory of Greece and/or Turkey – climate with Mediterranean influence.

Great variety of hydrogeological conditions is a characteristic feature of the groundwater in Bulgaria (Antonov et al., 1980; Boyadjiev, 1964):

- Many karstic springs drain elevated massives in many parts of the country, mainly in the regions of Fore-Balkan, Stara Planina, Strandja and Pirin Mountains, the Rhodopes, in the Kraishte geological region (the Upper Struma river basin).
- Important resources are formed in deep and shallow karstic aquifers in the North-East part of the country.
- Large groundwater resources are formed in thick alluvial and proluvial sediments of Quaternary age in the territories occupied by plains, valleys and kettles, etc.

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Such diversity is explained by various geological history and complicated tectonic structure of the territory of the country.

In the paper the seasonal variability of the groundwater regime for chosen aquifers in Bulgaria is analysed in the context of the natural conditions that determine their formation and regime. Some of the most important aquifers are studied.

Origin of data

All data originate from National Hydrogeological Network located in the National Institute of Meteorology and Hydrology. The Network that started in 1958-1960, includes sources and wells. Time series of spring discharges and water level in wells are used in this study. Stations having long observation periods (without significant impact of human activity on groundwater) are chosen.

At some springs the water level is recorded by limnigraph, at other stations water level is measured every day by observers. Measurement of spring discharge (using a current meter) is 12 times annually as usual. Using rating curve the daily data for spring discharge were obtained. For the majority of the springs the measurements of discharge are made once-twice in a month without daily observations on water level.

Some observational wells are equipped with level recorder, but the majority of them is observed one time (or several times) monthly. For the aim of this study, stations situated very close to rivers were not used. All stations showing significant impact of human activity on groundwater were eliminated.

For the aim of this study, perennial karstic springs with long observational period were chosen. The general characteristic of the selected springs is given in Table 1 with indication of their appurtenance to the respective territorial and hydrological unit.

Table 1 General characteristics of the karstic springs

Station N	Station name	Village	Situation	Geol. Index	Lithological composition
<i>Danube zone</i>					
25	Glava Panega	Zlatna Panega	Fore-Balkan	K ₁	limestone
450	Marata	Krushuna	Fore-Balkan	K ₁	limestone
<i>Black Sea zone</i>					
48	Kotelski	Kotel	Stara Planina	K ₂	limestone
83	Bash. kajnatzi	Trakijtzi	Strandja	T ₂ +J ₃	limest., marbles
<i>Aegean Sea zone</i>					
86		P.Skakavitza	Zemen mountain	T	limest., dolomites
59	Jazo	Razlog	Pirin mountain	Pt	marbles
59a	Kjoshka	Razlog	Pirin mountain	Pt	marbles
39a		Beden	Rhodopes	Pt	marbles

The regime of the groundwater was influenced by the drought during 1982-1994. The decrease of discharge for the springs was 20% for the period 1982-1994 and about 25% for the shorter period 1985-1994. Therefore they demonstrate evident vulnerability to drought. Similar results were obtained in all regions of Bulgaria. Porous aquifers formed in alluvial and proluvial sediments of Quaternary age were affected by this drought period as well - lowering of water level (0,3-0,4 m) was registered (Orehova et al., 2001, 2001a; Andreeva et al., 2001).

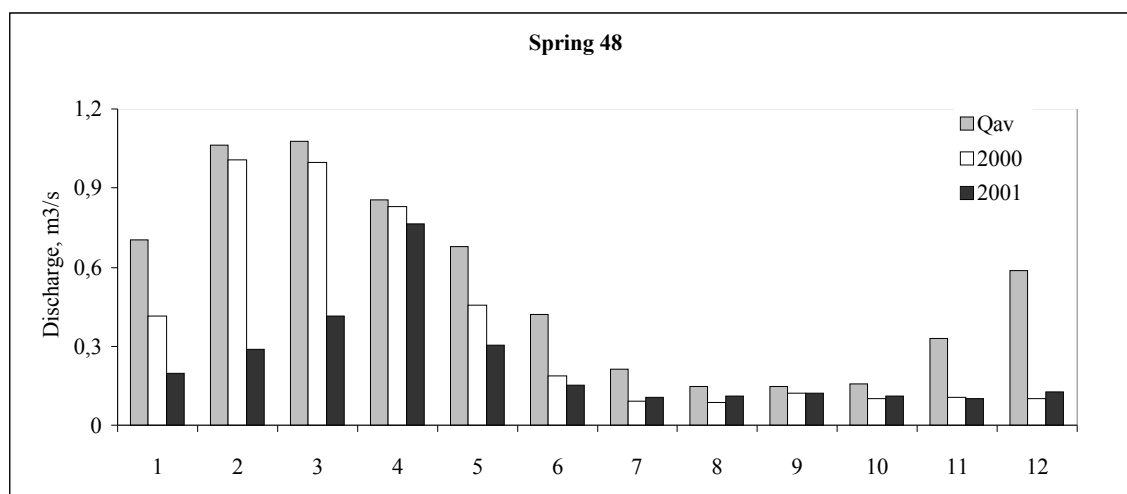


Fig 1 Seasonal variability of the discharge for spring 48

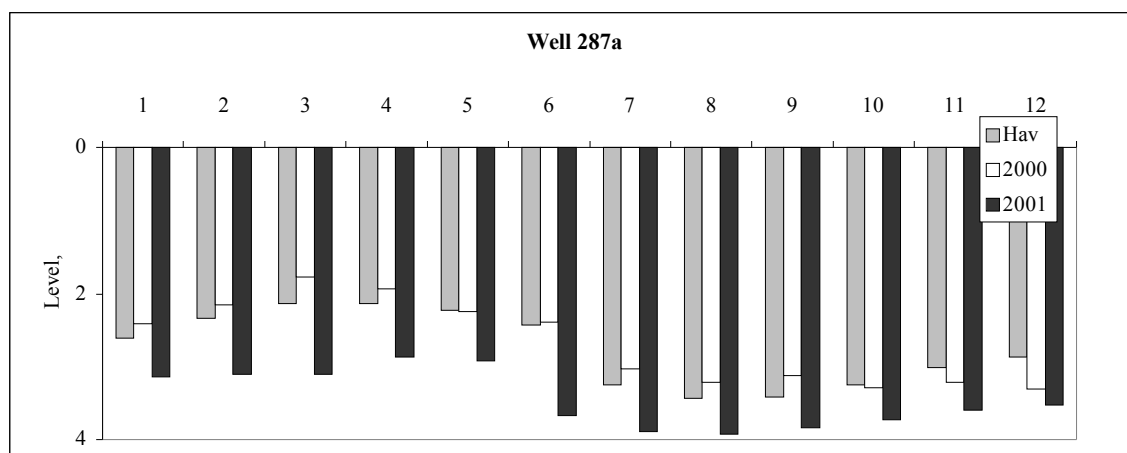


Fig 2 Seasonal variability of the water level for well 287a

From October 2000 till the end of the water year 2001 weather conditions were unfavourable for groundwater recharge in Bulgaria. The reduction of winter precipitation during the winter of 2001 had strong negative impact on the recharge of aquifers. Important decrease of spring discharges during the summer droughts in 2000 and 2001 was recorded, as well as falling of groundwater tables (Orehova, 2002a). In general, interannual regime is very sensible to changes in the recharge (except the stations showing low variability in their regime). Such sensibility is revealed in graphs for seasonal distribution of springflow for years 2000, 2001 compared with their norms for each month (see Fig. 1 as an example). For porous aquifers water levels registered in observational wells were lower compared with the long-term norms for the respective months. One example for water level variations in observational well N 287a is given (see Fig. 2) that refers to alluvial and proluvial sediments of Quaternary age in drainage basin of the river Maritza (Aegean zone), but this tendency was recorded in all territory of the country.

In Figures 1÷2 average values of discharges for springs and water levels for wells for the 1961-1990 period were used. This period was chosen taking into account the recommendation of WMO for defining of normals (WMO, 1984).

Seasonal variability for groundwater regime

Basic peculiarities of the interannual groundwater regime are characterised in this section. Seasonal variability of the springflow in relative units Q/Q_y (where Q is monthly discharge, Q_y – mean yearly value) is presented in Figures 3-4. Average values of discharges for the 1961-1990 period were used.

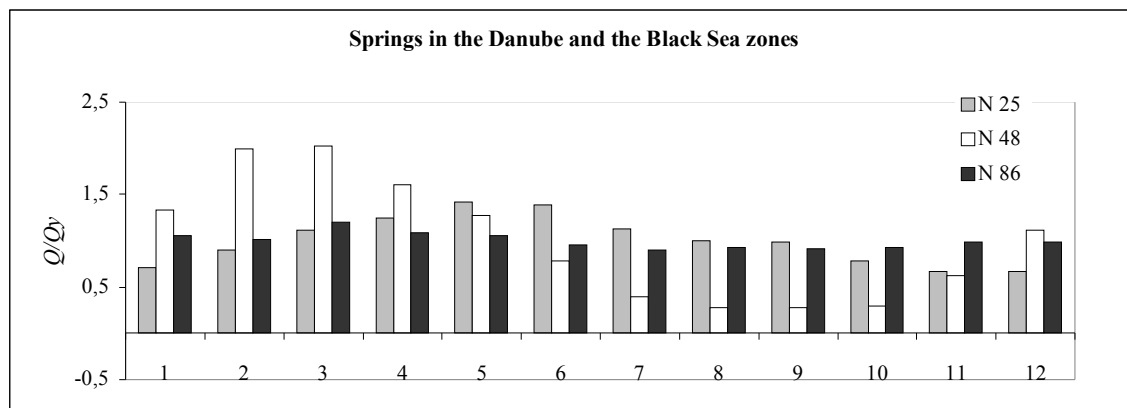


Fig 3 Interannual regime for selected karstic springs in the Danube and Black Sea zones

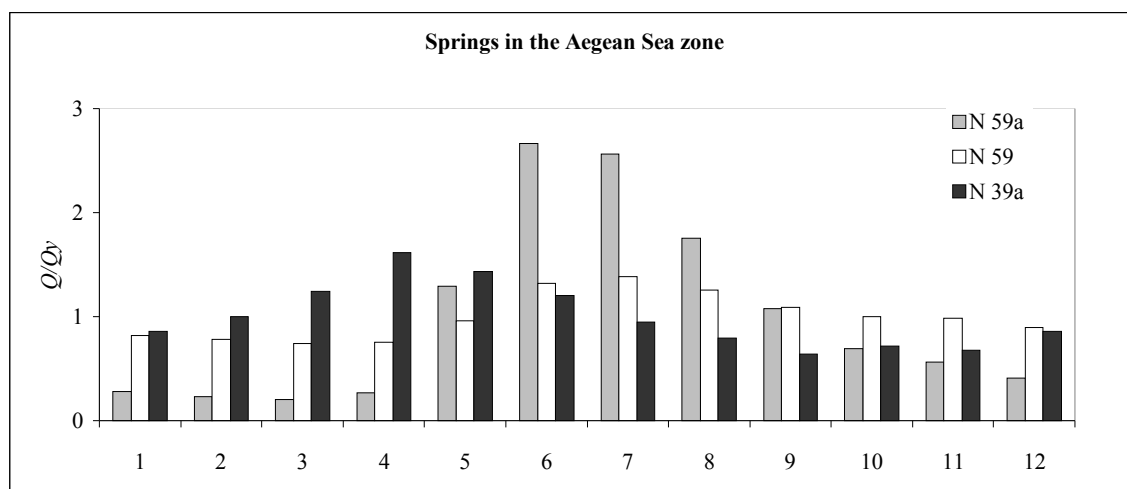


Fig 4 Interannual regime for selected karstic springs in the Aegean Sea zones

Most of the karstic springs in Bulgaria show large variation of discharge and has well-defined seasonal cycle. Only some springs show weak seasonal variation through the year. Such springs have specific formation:

- The greatest spring at village Zlatna Panega (N 25) has weaker seasonal variation through the year due to the water transfer from neighbour watershed and large territory that contributes to formation of its resources.
- Spring N 59 in Pirin mountain shows weak seasonal variation through the year. The combined analysis of variations of discharge and water temperature for springs in the region give unambiguous evidence that it drains deeper part of the Proterozoic marbles (Orehova, 2001). For this reason its seasonal variation is smoothed.
- Karstic springs in the Upper Struma basin have specific appearance. They are formed in fissured and karstified Triassic carbonate rocks with high dolomite component. Their low variability of spring flow throughout the year can be attributed to the structure of karstic

massifs: the predominance of small pores or thin fissures in the pore space providing large capacity of the rock massif.

As a rule, maximal discharges occur in spring due to snowmelt, however it occurs earlier or later depending on the altitude of the watershed and therefore the time of snowmelt. Most of springs have well-defined seasonal cycle with maximum of discharge in February-March (N 48), in April (N 39a), May-June (N 25), June-July (N 59a), July (N 59).

Minimal discharges are observed in August-September (N 48), September (N 39a), November-December (N 25), February-March (N 59a), and March - April (N 59).

The delay in the extremes for springs 59 and 59a is due to the situation of their watersheds in the high mountain Pirin. At the spring N 59 the maximum and minimum occur one month later than for the spring N 59a, and its seasonal cycle is more smoothed. These springs drain Proterozoic marbles (see Table 1).

For springs in the Danube zone the most usual case is maximal flows in early spring and minimal ones in October. Maximal discharge for spring N 86 in the Upper Struma basin (Aegean Sea zone) occurs mainly in March, and minimal – in July, but the interannual variations are smoothed (see Fig. 3).

Results obtained by Bojilova (2001) for generation of monthly and seasonal discharges for selected karstic springs in Bulgaria show applicability of stochastic models to reconstitute interannual distribution of the karstic flow.

The interannual variation of the groundwater temperature for karstic springs shows its close relation to the regime of the springflow. The joint analysis of spring discharge and water temperature for some Bulgarian springs confirmed the known peculiarity: the lower temperatures occur during the periods with high discharges (Orehova, 2001). In general, temporal variations of water temperature and discharge for spring give valuable information concerning special features of karstic massifs.

Interannual groundwater regime observed in wells shows similar tendencies related to the periods of the recharge to the aquifers. The highest levels are usual in spring when intensive recharge of the groundwater occurs due to snowmelt. The lowest levels are observed during late summer – autumn.

Methods, results and discussion

Seasonal pattern of flow distribution for karstic springs was analysed and estimated using some generalised characteristics (Fritsch, 2001). The behaviour of the ratios Q_{6M}/q_{6m} (runoff of the 6 wettest months over the 6 driest ones) and the ratio Q_M/q_m (runoff of the wettest month over the driest one) as a function of average spring discharge was analysed.

For this purpose the values of mean monthly discharges for each year were sorted from the maximal Q_M (in m^3/s) up to the minimal value q_m . The sums of the 6 wettest months Q_{6M} and the 6 driest ones q_{6m} were obtained for each year. These calculations were made for all springs presented in Table 1.

The results show that there was no significant correlation of the ratios Q_{6M}/q_{6m} or Q_M/q_m with the mean yearly discharge Q_y . All studied stations however showed high correlation ($r \sim 0.9$) between Q_{6M} and mean yearly discharge Q_y (Fig. 5-6). This conclusion is the same for all studied aquifers: in Proterozoic marbles (springs N 59, 59a, 39a), Triassic limestones and dolomites (spring N 86), Cretaceous limestones (springs N 25, 48). This means that the recharge predetermines the average value of spring discharge.

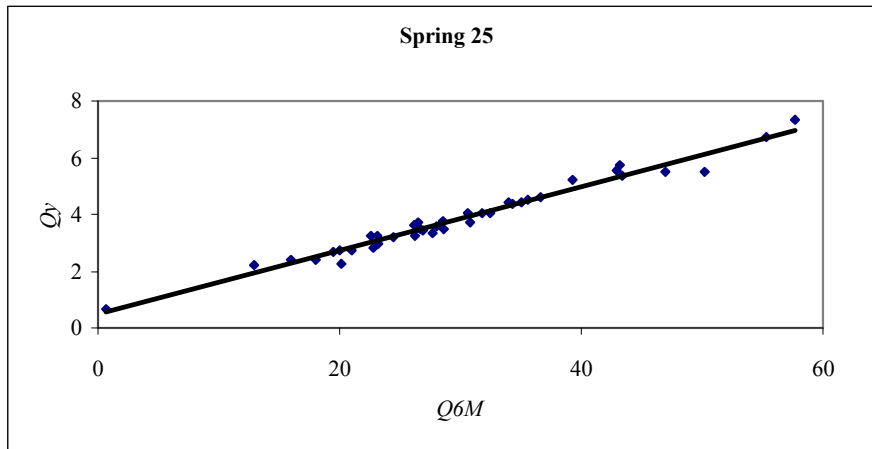


Fig 5 Relation between $Q6M$ and mean yearly discharge for spring 25

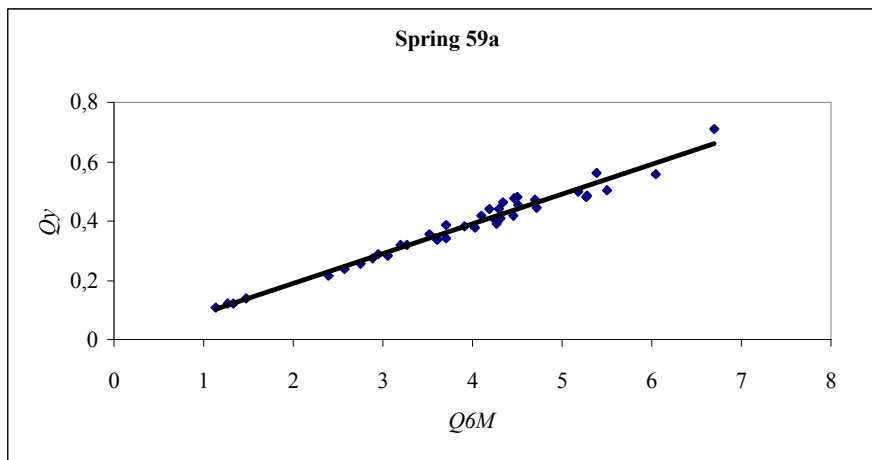


Fig 6 Relation between $Q6M$ and mean yearly discharge for spring 59a

Similar results were obtained for observational wells in porous aquifers related to proluvial-alluvial Quaternary sediments. For them the values of mean monthly water levels for each year were sorted from the highest level HM (in m) up to the lowest value hm . The sums of the 6 wettest months $H6M$ and the 6 driest ones $h6m$ were obtained for each year. High correlation ($r \sim 0.9$) between $H6M$ and mean yearly water level Hy was obtained for studied observational wells (see Fig. 7 as an example).

No significant correlation was obtained between $Q6M$ of the previous year and the average discharge for the next year. This fact does not allow forecasting on this basis.

The seasonal variability of the springs to some extent is related with their vulnerability to drought. More precisely, the resistance to drought for karstic springs is determined by time-series of the minimal yearly discharges. The assessment of vulnerability to drought for some karstic aquifers showed that the degree of their resistance depends on geological and structural peculiarities of the karstic massives (Orehova, 2002b).

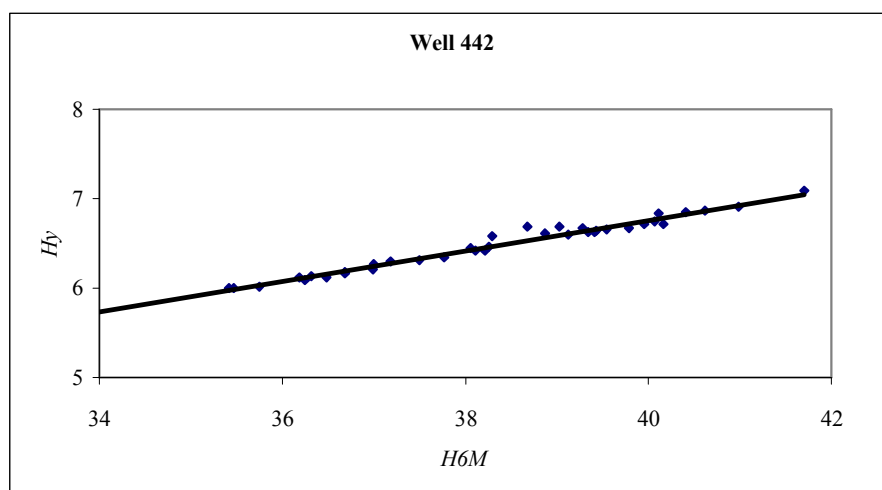


Fig 7 Relation between $H6M$ and mean yearly water level for well 442 from Danube zone

Conclusions

Seasonal variability of the groundwater regime for several aquifers in Bulgaria was studied. Most of the karstic springs in Bulgaria show large variation of discharge and has well-defined seasonal cycle. Springs showing weak seasonal variation through the year have specific formation.

The seasonal pattern of the flow distribution is influenced by variations in the groundwater recharge and reflects all complex of natural conditions. The conclusion is that the mean yearly value of the spring discharge is determined by the value of the groundwater recharge that is connected with the discharge of the 6 wettest months.

This conclusion is the same for all studied aquifers: in Proterozoic marbles, Triassic limestones and dolomites, Cretaceous limestones, and proluvial-alluvial Quaternary sediments.

Some other peculiarities of the seasonal variability for the chosen aquifers in Bulgaria were outlined. They are related to different elevation of the watersheds and therefore different periods of snowmelt, to geological and structural peculiarities of the karstic massives. In general, seasonal variability of the groundwater regime reflects variations in the recharge to the aquifers (except the stations showing low variability in their regime).

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