HYDROLOGICAL ASSESSMENT FOR SELECTED KARSTIC SPRINGS IN THE MOUNTAIN REGIONS OF BULGARIA

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Abstract: Karstic water is an important source of water in the rural areas of Bulgaria. In this study, we estimate the impact of climate variability on the regime of karstic springs of two mountainous regions of the country. Since 1981 Bulgaria has experienced a continuous decrease in rainfall combined with an increase in air temperature. As a result, ground water levels and spring discharge have decreased. Data from three karstic springs were used. The springs refer to karstified Proterozoic marbles. Their watersheds are situated in the Pirin and Rhodopes mountains located in the southwestern part of Bulgaria. The infiltrated snowmelt water is the main source of spring recharge. The springs are included in the National Hydrogeological Network. Time series of spring discharge were studied, with a special focus on the drought period during 1982–1994, which was compared to the 1960–2001 observation period. The 1982–1994 drought period in Bulgaria also considerably influenced the evaluated springs. The strongest reduction in spring discharges was registered during the period 1985–1994. After 1996, the yearly average discharges have tended to reach their multi-annual average values. However, reduced values of spring discharges were observed again in 2000 and 2001. The quantification of the effect of a documented long drought period is of great significance for the prediction of the effects of future climatic change on groundwater resources.

Keywords: karstic springs, spring discharge, hydrological assessment, drought, multi-annual variations

E. Wiegandt (ed.), Mountains: Sources of Water, Sources of Knowledge, 265–280.

1. INTRODUCTION

Since 1981 in Bulgaria, there has been a continuous decrease in rainfall combined with an increase in air temperature, resulting in reduced river flow. The ensuing drought has elicited great interest because of its relation to global climate change, which is expected to threaten water resources (World Data Center, Trends' 93 1994; Arnell 1999).

The drought period may be considered as a model for future global changes. A recent study of water resources during the drought period (Gerassimov et al. 2001) describes the general characteristics for this period for the whole of Bulgaria. The study concerns the three main hydrological zones in Bulgaria: (1) the zone with direct discharge to the Danube River; (2) the zone with direct discharge to the Aegean Sea; and (3) the zone with influence of the Black Sea.

In addition to the study of precipitation and river flow, some analysis of groundwater variation has also been undertaken (Gerassimov et al. 2001; Orehova and Bojilova 2001). In the present study, more explicit information is given for the Aegean Basin, namely for the watersheds that are situated in the Pirin and Rhodopes mountains located in the southwestern part of Bulgaria. This basin has its source in the mountains, often referred to as "water towers." With regard to water resources, the importance of the mountainous regions is primarily based on enhanced precipitation due to the orographic effect. Colder temperatures at higher altitudes result in lower evapotranspiration rates, with mountainous areas providing the greater part of the fresh water flowing downstream. However, these water towers are subject to droughts, thus producing unfavorable impacts on water resources.

The aim of the present study is to characterize the general behavior of a few selected springs. In this regard, the influence of the drought during 1982–1994 on the regime of selected karstic springs was estimated. For this reason the studies of variations in the spring discharge were made for the longer 1960–2001 period.

2. GENERAL CHARACTERISTICS OF THE DROUGHT PERIOD

The general characteristics of the drought period are presented in the monograph *Drought in Bulgaria: A Contemporary Analogue for Climate Changes* (Gerassimov et al. 2004).

2.1. Available Data

Eight representative hydrological stations for the Aegean Basin were used (Gerassimov et al. 2001 and 2004). Observation data on water levels for rivers were available since 1909, and regular water discharge measurements started in 1936.

Data series for precipitation and air temperature were obtained at the base of all rain gauge and meteorological stations in the territory of Bulgaria. They were extrapolated using correlation and regression analysis, taking into consideration the altitude of stations. The number of stations for precipitation and air temperature is given in Table 1.

Table 1: Used Data Series with Annual Values for Precipitation and Air Temperature (after M. Genev et al. 1998).

Area	Precipitation stations (P), number	Temperature stations (T), number
Aegean Basin	114	69
Bulgaria total	300	169

2.2. Analysis of Multi-Annual Variations of Air Temperature, Precipitation, and River Flow

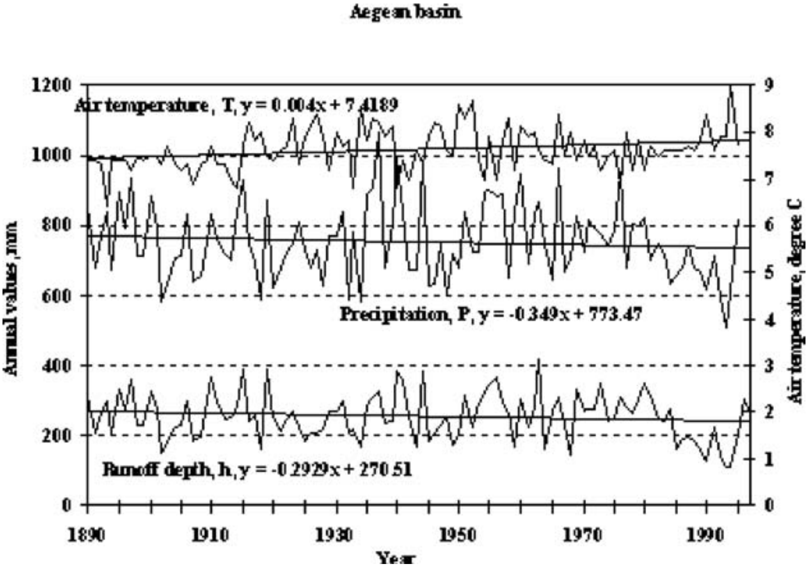

Figure 1: Mean Annual Values of Air Temperature T, Precipitation P, and River Flow h (as water layer) for the Aegean Basin (after Gerassimov et al. 2001).

Data extrapolation and weighting made it possible to calculate the mean annual temperature, precipitation, and river discharge for the 1890 to 1995 period for each of the three Bulgarian hydrological basins.

A strong decrease in precipitation and runoff was registered in the Aegean hydrological zone (see Figure 1).

2.3. Definition of the Drought Period for Precipitation and River Flow

The drought period 1982–1994 for discharges and precipitation is defined and analyzed by Gerassimov et al. 2001. The statistical structure of the period is represented by two basic parameters—mean value $\overline{X}$ and standard deviation σ_X—and is given in Table 2. The statistical parameters are compared with values from the longest period of data between 1890 and 1995. Table 2 shows that the chosen estimators ($\overline{X}$ and σ_X) are considerably lower from their values over the 106-year period.

Table 2: Statistical Structure of the Drought Period 1982–1994: $\overline{X}, \sigma_X, Cv$ and Their Deviation in Relation to the Period 1890–1995 (Kx, KT, Kcv) (after Gerassimov et al. 2001).

Area	h, P	$\overline{X}_{13}$ mm	$K_X = \frac{\overline{X}_{13}}{\overline{X}_{106}}$	σ_{13} mm	$K_\sigma = \frac{\sigma_{13}}{\sigma_{106}}$	Cv_{13}	K_{Cv}
Aegean Basin	h	182.6	0.719	52.7	0.791	0.289	1.103
	P	658.7	0.873	67.2	0.626	0.102	0.718
Bulgaria total	h	138.2	0.695	41.7	0.747	0.302	1.075
	P	640.2	0.877	66.5	0.639	0.104	0.732

During the 1982–1994 period, the runoff and precipitation in Bulgaria are below their norms. This period is characterized by a 31 percent decrease of runoff in comparison to the norms for the 1890–1996 period (Gerassimov et al. 2001). The shorter period of 1985–1994 gives a stronger reduction in discharge. If we apply climate change estimations given in Arnell 1999, the assessed reduction of future river flow in Bulgaria will be 25–50 percent. It is possible to make a comparison of results obtained for the 1982–1994 drought period in Bulgaria with Arnell's scenario as well as with others.

3. DESCRIPTION OF THE STUDY AREAS

For the purpose of this study, two study regions were selected (Figure 2). They are situated in the Pirin and Rhodopes mountains located in the southwestern part of Bulgaria. Both study areas belong to the Rila-Rhodope Geomorphological Region. The climate of the northwestern part of Bulgaria is temperate with Mediterranean influence (Koleva and Peneva 1990).

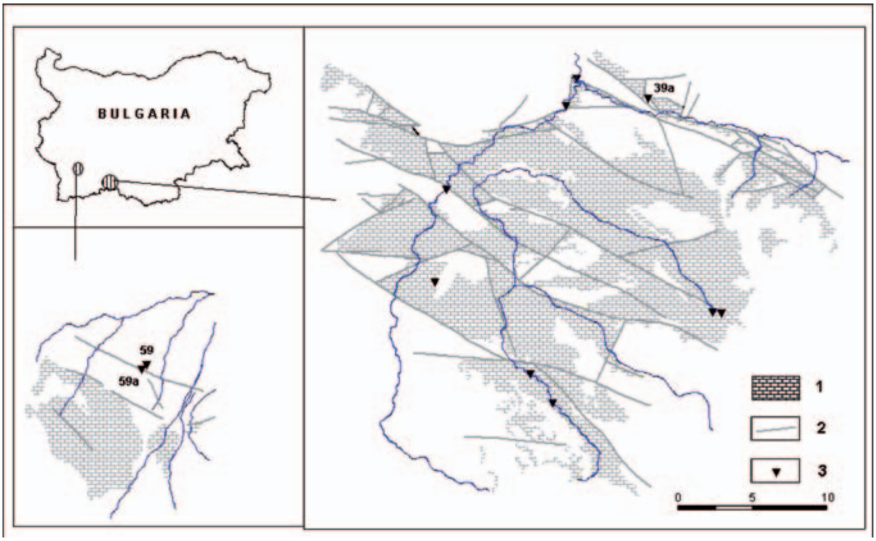

Figure 2: Map of the Razlog and Nastan-Trigrad Karst Basins (prepared by A. Benderev): (1) Marbles; (2) Faults; (3) Main Springs.

3.1. Razlog Karstic Basin

The first study area refers to the Pirin mountain, which in its modern boundaries corresponds to the Pirin neotectonic horst (Zagorchev 1995). In northern Pirin, Precambrian marbles of the Dobrostan Marble Formation (Rhodopian Supergroup) are developed, with a thickness of more than 1,000 m (Zagorchev 1995, 2001). Marbles construct the highest part of the mountain from 950–1,000 to 2,914 m above sea level (a.s.l.). Mostly vertical caves are developed there as a result of karstification of marbles (Bakalov et al. 2002).

The Razlog karstic basin (Boyadjiev 1964; Antonov and Danchev 1980) is drained by several springs, of which the Jazo and Kjoshka are the most important. These are located in the preserved area of the Pirin

Mountain National Park and are included on the list of the UN World Natural Heritage sites.

Due to high karstification of marbles, there is no surface runoff in the region. Scant vegetation within the alpine belt and low temperatures impose low evapotranspiration (<30 percent). Large values of yearly precipitation (800–1,000 mm in high parts of the mountain), provide considerable recharge to the ground water. Besides this, karst waters are fed by inflow from rivers. The karst water flows to the north and northeast towards Razlog kettle. The spring issues are manifested among the proluvial fan at the periphery of the Pirin horst (Bakalov et al. 2002). This basin is referred to the watershed of the Mesta River.

3.2. Nastan-Trigrad Karst Basin

The second study area refers to the Nastan-Trigrad karst basin situated in the Central Rhodopes (Boyadjiev 1964). Precambrian marbles of the Dobrostan Formation with a thickness exceeding 2,000 m are exposed in the drainage basin of the river Vucha at altitudes between 700 and 2,190 m. The accumulation of large resources of karst waters is related to intensive and long-lasting karstification and to tectonic movements in the region (Jaranoff 1959).

According to data obtained from meteorological stations, yearly precipitation sums in the region are in the range of 680 to 900 mm. The recharge of the aquifer is due to precipitation and inflow from rivers that enter into the karst terrain (Benderev et al. 1997). The Nastan-Trigrad karst basin is drained by many springs. For the purpose of this study, the Beden spring (N 39a) was selected. The recharge of karstic water is mainly due to snowmelt. The general characteristic of the three karstic springs from both study areas (Razlog and Nastan-Trigrad karst basins) is presented in Table 3.

Table 3: General Characteristics of the Karstic Basins. (for the climatic period 1961 – 1990).

Parameter	Unit	Jazo N 59	Kjoshka N 59a	Beden N 39a
Spring altitude	m a.s.l.	913	941	786
Mean discharge*	m^3/s	1.142	0.417	0.819
Location		Pirin	Pirin	Rhodopes
Village		Razlog	Razlog	Beden
Geological age		Pt	Pt	Pt
Lithological composition		marbles	marbles	marbles

4. SPRING VARIABILITY ANALYSIS

4.1. Information Database

The selected springs (see Table 3) are included in the National Hydrogeological Network of the National Institute of Meteorology and Hydrology, Sofia. The period beginning with the first observation (between 1959 and 1964) for the respective station was investigated in this study. The frequency of measurements was noted 12 times for each year using a current meter. Water stage and water temperature at the mouth of the spring were measured mainly by observers; recorders were operating only at limited number of stations. Using a rating curve, the daily data of water stage were transformed into spring discharge. The groundwater quality was determined four times per year for selected springs. Basic components like nitrates were defined.

Whereas in the springs of Kjoshka and Beden no direct anthropogeneous impact was observed, the water of the Jazo spring was used for domestic, industrial, and irrigation purposes. For the latter, the gauging station is located after water has been supplied to the three sectors. The total amount of water used before the gauging station is estimated to be 21 percent of the total spring discharge. For this study, water usage has been assumed to be constant through the years. However, the domestic and industrial uptake of water started prior to the first observation period while the water uptake for irrigation purposes started after the gauging station was installed.

4.2. Regime of Spring Flow

The regime of the selected springs is described by time series data obtained from the National Hydrogeological Network. The period under study begins from the first observation recorded for the respective station.

As a rule, maximal discharges occur in spring or summer due to snowmelt. The delay in the extremes for springs 59 and 59a is due to the location of their watersheds in the high mountain Pirin.

Beden spring has maximal discharge in April–May and minimal discharge in September–October. Kjoshka spring has a well-defined seasonal cycle with maximum discharge in June and minimum in February–March. At the Jazo spring the maximum and minimum occur one month later and its seasonal cycle is smoother. It shows weak seasonal variation over the year.

Seasonal variability of the spring discharge for the selected springs in relative units Q/Qy (where Q is monthly discharge, Qy—mean yearly value) is presented in Figure 3. Average values of discharges for the 1961–1990 period were used.

Results obtained by Bojilova (1994 and 2001) for the analysis and generation of monthly and seasonal discharges for the studied karstic springs in Bulgaria (Jazo, Kjoshka, Beden) show applicability of stochastic models to reconstitute interannual distribution of the karstic flow. E. Bojilova (2004) applied the method of composition to the Beden and Jazo springs to extend the probability curve of the empirical distribution of both springs. The method makes possible the estimation of quantiles in the range of very low probability of occurrence.

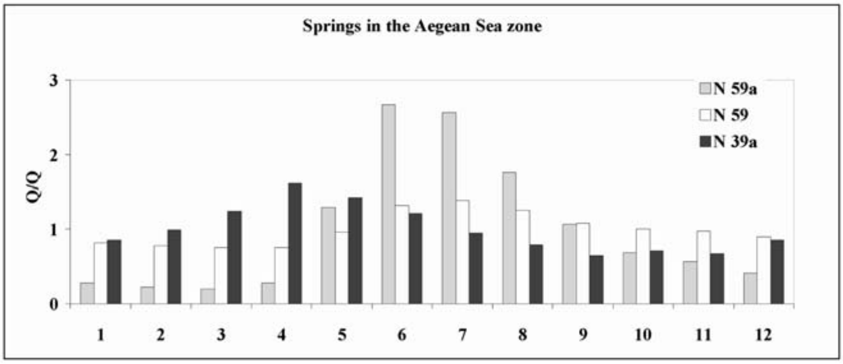

Figure 3: Monthly Regime for Selected Karstic Springs in the Aegean Sea Zones (Orehova, ICHE 2002).

4.3. Regime of Groundwater Temperature

Orehova (2001) made a comparative analysis of variations in water temperature for the chosen springs. Time series of water temperature and spring discharge for the period 1993–1997 were analyzed, showing that each spring has its own temperature behavior.

The frequency distribution of the water temperature is presented in Figure 4. The distribution obtained is bimodal for all springs. Comparative temporal variations for different springs are given in Figure 5. The Jazo and Kjoshka springs are located in the same region but their temperature difference is about two degrees. The altitude of the outflow for Kjoshka spring is higher that for Jazo spring (see Table 3), therefore it is supposed that Kjoshka drains the upper part of marbles, and consequently has a lower temperature and a well-defined seasonal cycle.

The temporal variation of water temperature (minimal monthly temperature) and spring discharge (average month value) is presented in Figures 6–8. The time series are presented in deviations:

$$\psi = \frac{X - \overline{X}}{\sigma_X}, \tag{1}$$

where $\overline{X}$, σ_X are average values and standard deviations respectively.

There is a clear correlation between water temperature and discharge (for some cases the best correlation is obtained for the logarithm of the discharge). The lowest temperatures are observed when spring discharge is at a maximum (see Figures 6 to 8). This corresponds to snow melt and to a massive input of water at low temperature into the aquifers. The recharge events always lead to a decrease in spring water temperature in relation to background temperature.

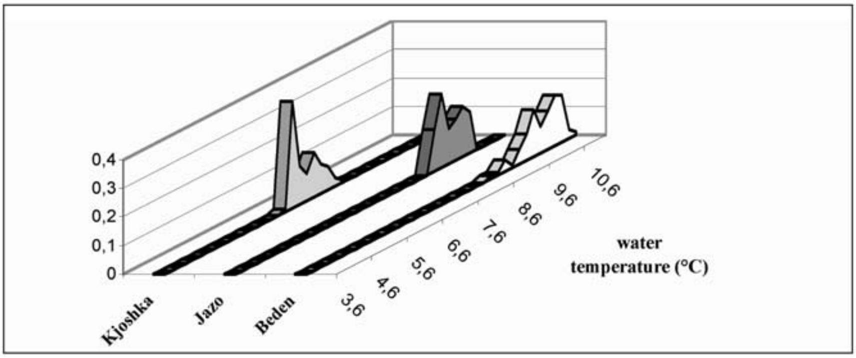

Figure 4: Frequency Distribution of Temperature for the Chosen Karstic Springs.

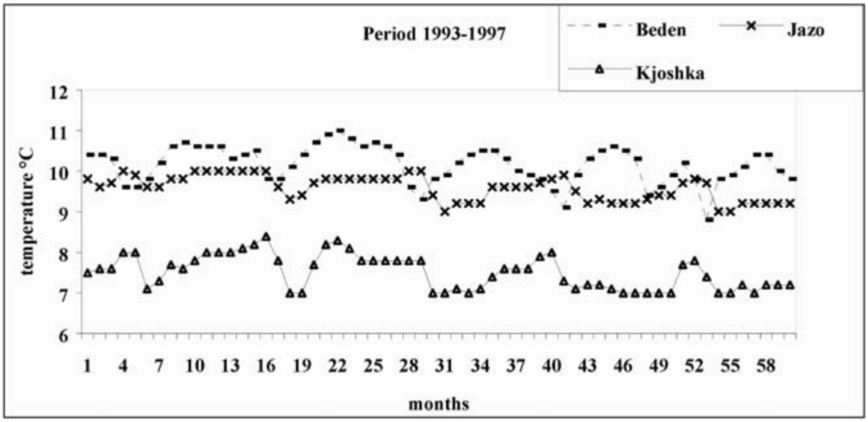

Figure 5: Comparative Temporal Variations of Water Temperature for All Springs.

As discharge falls, the water temperature rises. All studied springs reach maximum temperatures during baseflow period.

The following conclusions can be made (according to Orehova 2001):

- The joint analysis of spring discharge and water temperature confirms some known characteristics of karst springs: the lower temperatures occur during the periods with high discharges.
- All studied springs reach maximum temperatures during baseflow period.
- The time series of the two springs situated in Pirin mountain are asynchronous to springs from the other regions. This is due to the fact that their watersheds are located at much higher altitudes and therefore the snowmelt occurs some months later.

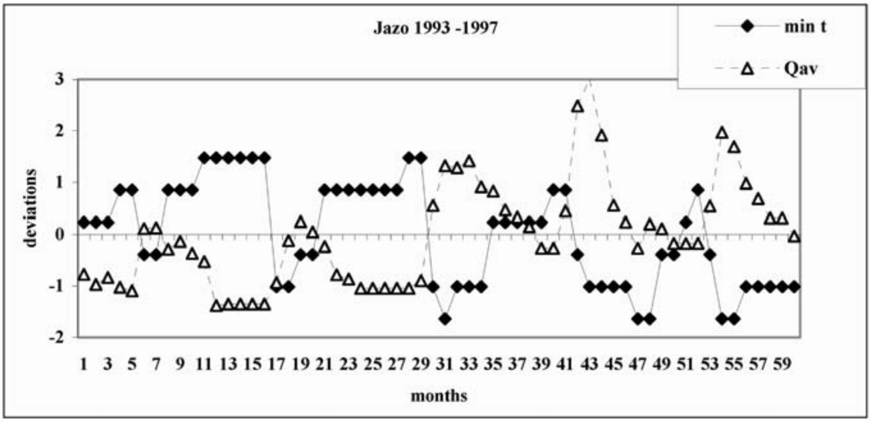

Figure 6: Temporal Variations of Water Temperature and Discharge for Jazo Spring.

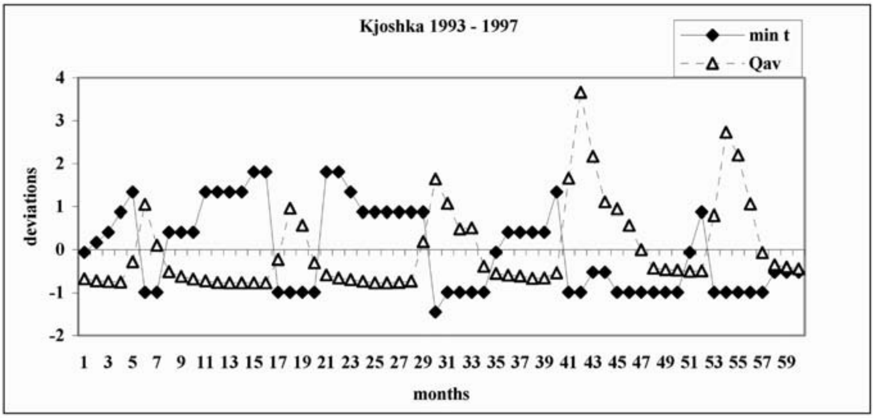

Figure 7: Temporal Variations of Water Temperature and Discharge for Kjoshka Spring.

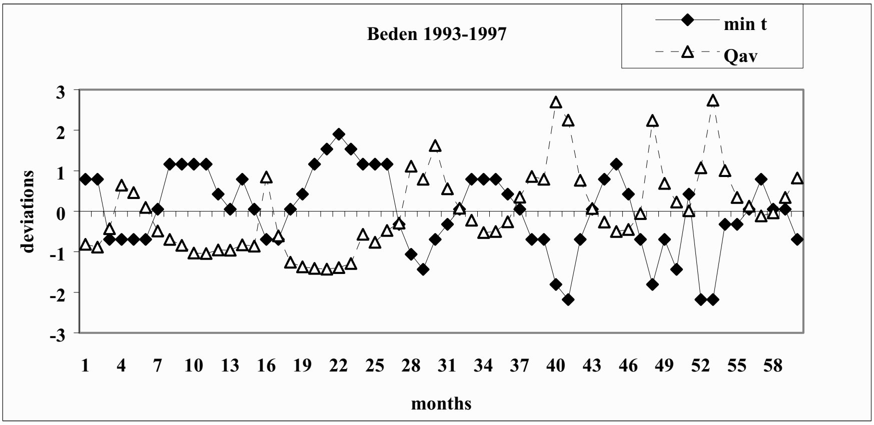

Figure 8: Temporal Variations of Water Temperature and Discharge for Beden Spring.

Water temperature gives valuable information on karst systems. The two springs from Razlog karst basin appear near one another but at different altitudes (see Table 3). Thus their comparative analyses of the discharge and water temperature are useful. Orehova (2001) showed that significant discharge variation and lower temperature give evidence that the Kjoshka spring drains the upper part of marbles, and Jazo their deeper part. Bakalov et al. (2002) also drew the same inference, subjoining lower total mineralization of the upper spring (235 mg/l for Kjoshka and 253 mg/l for Jazo on average for the period 1980–1991).

4.4. Quantitative Assessments of the Effect of the Drought Period to Groundwater

For a quantitative assessment of the 1982 to 1994 drought period the mean values for the periods 1960–1996, 1960–1981, 1982–1994 and 1985–1994 have been calculated. The percent deviation is obtained by the following equation:

$$\varepsilon = \left(\frac{\overline{X}_n}{\overline{X}_N} - 1 \right) 100\% \tag{2}$$

where n refers to the short period and N for the whole period.

Deviations for shorter periods in comparison to the longest one are presented in Table 4, as well as data for the Aegean Basin and total river discharge for Bulgaria (Orehova and Bojilova 2001a).

Table 4: Deviation of Average Values for Discharges for the Periods 1960–1981, 1982–1994, and 1985−1994 from the Mean Values for the 37-Year Period of Observation. (for the period 1890–1995)

Basin	**Station**	**1960-1996** **ε, %***	**1960-1981** **ε, %**	**1982-1994** **ε, %**	**1985-1994** **ε, %**
Mesta	Karstic Spring – 59		14.7	−22.9	−25.9
Mesta	Karstic Spring – 59a		18.0	−24.8	−32.8
Vacha	Karstic Spring – 39a		14.6	−19.3	−30.0
Aegean	Aegean drainage basin	−6.0	14.6	−25.3	−34.0
Bulgaria	Total river discharge	−3.9	17.0	−27.7	−35.8

4.5. Chronological Structure

The time series of spring discharge are analyzed using the method of double-mass curves. Figure 9 is an example of an application of this method.

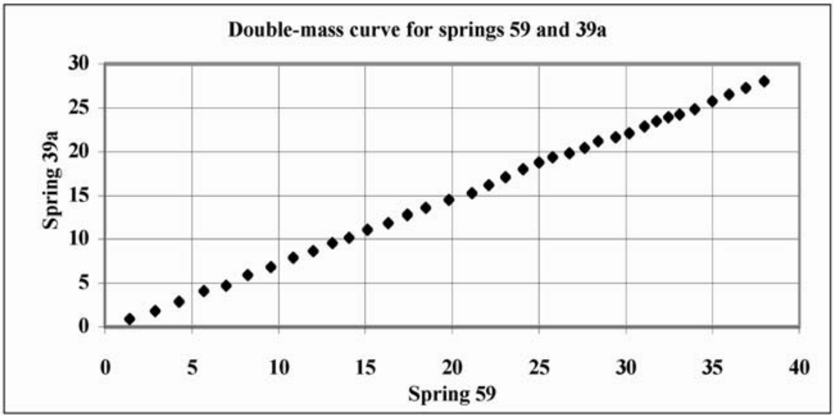

Figure 9: Double-Mass Curve for Springs 59 and 39a (m^3/s).

The double-mass curve is smooth and without significant change in the direction. From this analysis we can infer that there is no visible anthropogenic impact on the regime of karstic springs.

The chronological structure of the investigated periods is presented in Figures 10 to 12. The graphs represent the annual discharge for springs and Aegean drainage basin in deviations using equation (1). For the purpose of this study, the existing data for Aegean Sea basin for the period 1960–1997 were used.

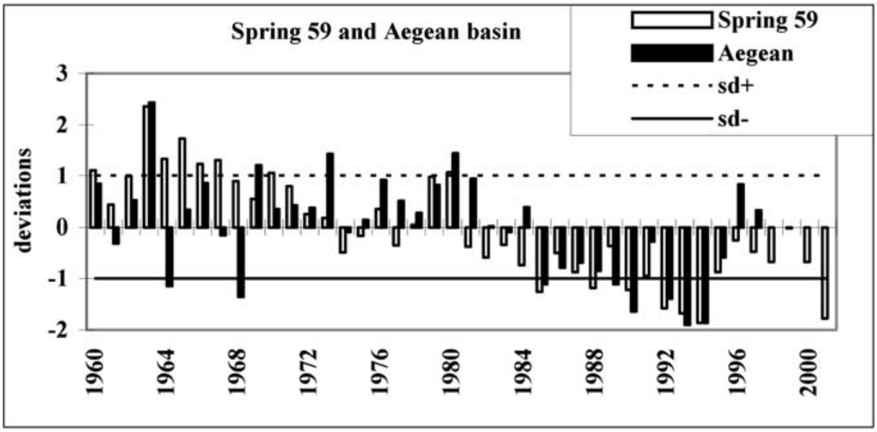

Figure 10: Discharge for Spring 59 and Aegean Basin in Deviations ψ.

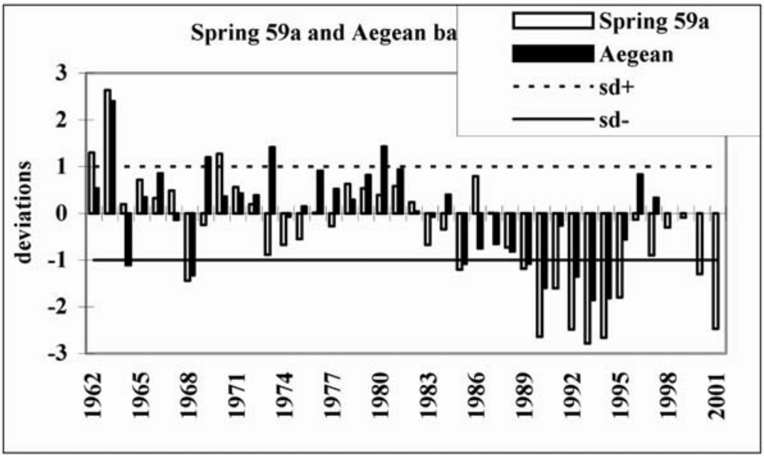

Figure 11: Discharge for Spring 59a and Aegean Basin in Deviations ψ.

The information presented in Table 4 and Figures 10 to 12 provides the following results:

- The drought period 1982–1994 and especially the short one between 1985–1994 are characterized by considerable reduction in karstic spring discharges (up to 25–30 percent);
- The chronological structure of the karstic spring discharge is similar to that of the river runoff in the Aegean zone;
- The minimal values of spring discharges are registered in 1993–1994. Since 1995–1996 the yearly average discharges tend to reach their multi-annual average values.

- Results also show an important reduction in discharge (for springs 59a and 39a) for years 2000 and 2001 (about 30 percent and 40 percent, respectively).

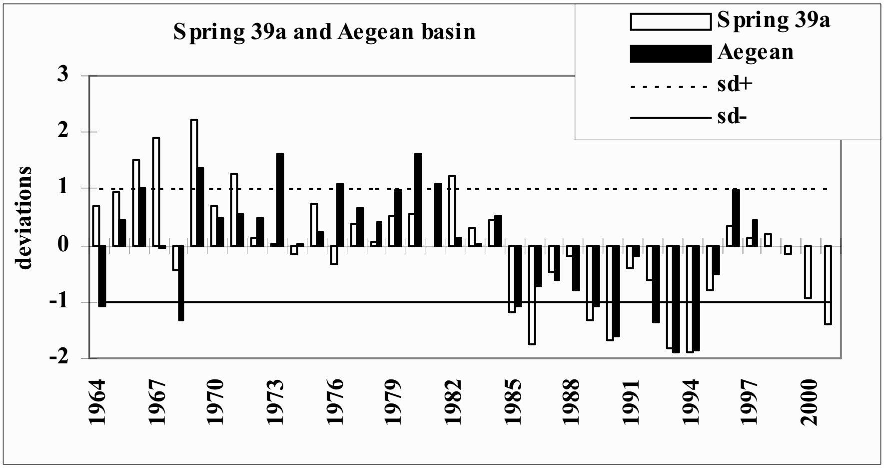

Figure 12: Discharge for Spring 39a and Aegean Basin in Deviations ψ.

4.6. Interannual Regime of Springs during Droughts

During our analyses, data for different periods were evaluated. The first is the climatic period recommended by WMO 1961–1990; the second is the drought period between 1982–1994; and third are the values for 2001 (Figures 13–15). The comparison between climatic and drought periods shows reduction of monthly spring discharge of up to 30–35 percent. Year 2001 shows strong reduction of discharges, especially during the winter months (Orehova 2002a). According to Andreeva and Orehova (2004), 2001 had a mild winter. Besides higher temperatures, mild winters are characterized by lower precipitation, and thus lead to reduced recharge to the aquifers.

For surface runoff, M. Genev assessed the probability structure of drought in Bulgaria, evaluating the extended period 1982–2001. He established that during the period under investigation a very low probability of occurrence was observed. According to his study, it is not possible to clearly say where exactly is the end of the drought period observed on the Balkan Peninsula (Genev 2004).

Our recent research confirms previously reached conclusions that the reduction of precipitation during mild winters has a strong negative influence on groundwater recharge (Andreeva and Orehova 2004). The obtained results can be used for the estimation of long-term spring variability.

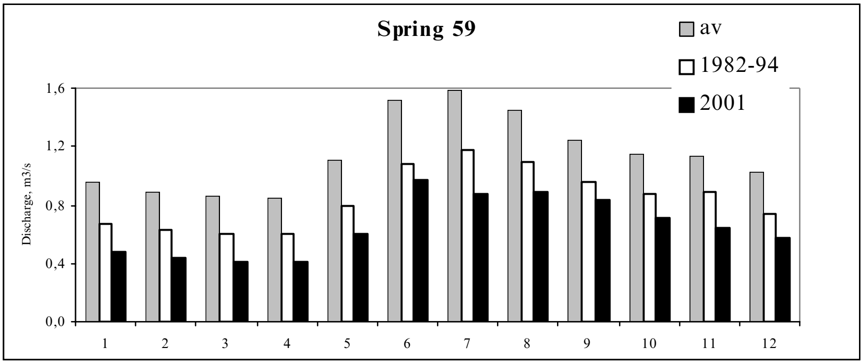

Figure 13: Monthly Values for Jazo Spring.

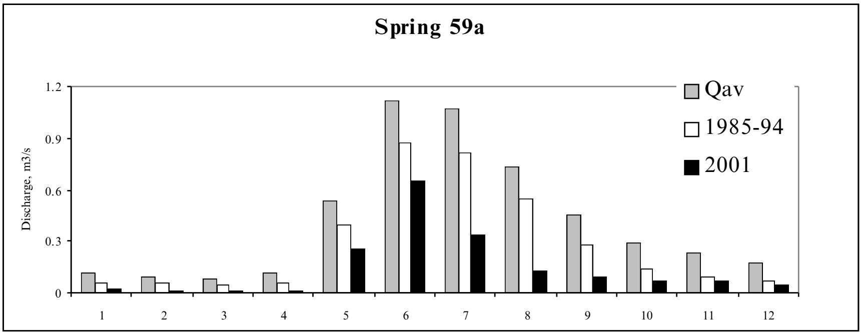

Figure 14: Monthly Values Kjoshka Spring.

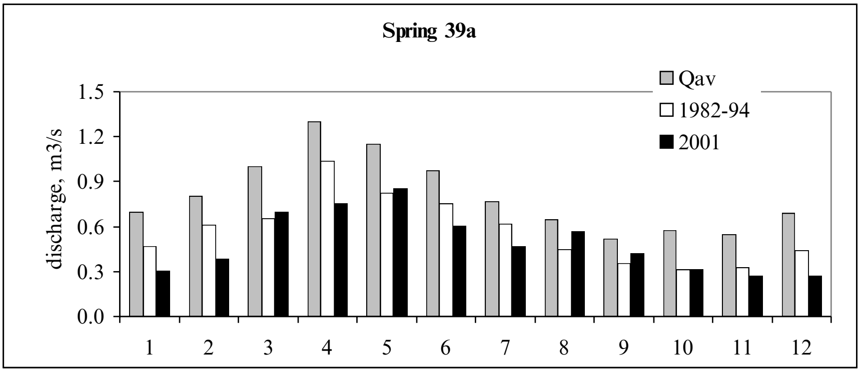

Figure 15: Monthly Values for Beden Spring.

A rapid response to the reduction of recharge was observed for the studied springs from mountainous areas. As the recharge of these springs is mainly due to snowmelt, low precipitation during mild winters had strong negative influence on the spring discharge, which is observed during the period of high flow. Such strong dependence would make the modeling of spring discharge, based on precipitation and air temperature, possible.

5. CONCLUSIONS

In this study, we estimated the impact of climate variability on the regime of selected karstic springs of two mountainous regions in Bulgaria. Since 1981 a continuous decrease in rainfall combined with an increase in air temperature was registered. As a result reduced river runoff and spring discharge were observed.

For the present study, data were used from three karstic springs whose watersheds were located in the Pirin and Rhodopes mountains in the southwestern part of Bulgaria. For these springs, the infiltrated snowmelt water forms the main source of spring recharge.

The aim of the study was to evaluate time series of spring discharge with a special focus on the drought period 1982–1994, which was compared to the 1960–2001 observation period. The drought period considerably influenced the evaluated springs. The strongest reduction in spring discharges is registered during the period 1985–1994. After 1996 the yearly average discharges tended to reach their multi-annual average values. However, reduced values of spring discharges were observed again during 2001.

Spring discharges were analyzed using the method of double-mass curves. The chronological structures of time series for the three karstic springs resemble each other, showing the similarity in their geological and climatological context. The quantification of the effect of a documented long drought period is of great significance for the prediction of the effects of future climatic change on spring discharge and groundwater resources.

The chronological structure of the karstic spring discharge in the studied area is similar to that of the river runoff in the Aegean zone with minimal values for spring discharges in the years 1993–1994.

Results obtained can be used for the estimation of long-term spring variability. A fast response to reduction of recharge was observed for the studied springs. As the recharge of these springs is mainly due to snowmelt, low precipitation value during mild winters had strong negative influence on the spring discharge. The strong dependence would give rise to the possibility of modeling spring discharge based on precipitation and air temperature.