TEMPORAL VARIABILITY OF THE GROUNDWATER RECHARGE: CASE STUDIES FROM BULGARIA

Assoc. Prof. Dr. Tatiana Orehova

Geological Institute - BAS, **Bulgaria**

ABSTRACT

Groundwater recharge in Bulgaria is characterized by well-expressed seasonal and interannual variability. The long-term drought period (1982-1994) had harmful influence on the groundwater replenishment. As a result, substantial reduction in spring discharges and declining groundwater levels has been observed. During the last decades, great interest has been generated for the topic "climate change and groundwater" all over the world. The urgency of this research is explained by the forecasted reduction in precipitation sums for Southern Europe, with consequent decline of the groundwater resources.

There are different mechanisms of groundwater recharge, as well as numerous methods and tools to define it. The program WATBUG based on a soil moisture balance model was used to quantify groundwater recharge for the two study sites: the Kyustendil Valley (western Bulgaria) and the Haskovo Valley (southern Bulgaria). The program was run for the period 2000-2005, using both daily and monthly meteo-data. This short period includes both dry and wet years.

The present study confirms substantial temporal variability of the groundwater recharge. Using monthly input data leads to underestimation of the recharge rate. Daily data are necessary to obtain reliable estimates of the groundwater recharge based on the soil moisture budget model.

Keywords: groundwater, recharge, soil moisture budget, drought, Bulgaria

INTRODUCTION

The theme “climate variability and groundwater” shows increasing interest during last years all over the world [1, 2]. Groundwater in Bulgaria is rather sensitive to droughts, as was established during the long-lasting drought period 1982-1994 [3, 4]. Taking into account significant climate variability and possible future climate change, there is a real threat to groundwater resources in Bulgaria that are widely used for potable water, irrigation and industry.

Evaluation of the recharge rate is important for various applications related to water management: groundwater resources assessment, flood prediction, estimating impact of droughts, etc. Groundwater recharge provides recovery of water in aquifers. It is defined as “the downward flow of water reaching the water table, forming an addition to the groundwater reservoir” [5]. The climate, topography, geology, soil and vegetation of a site control the location and timing of the recharge [6]. Numerous studies all over the world revealed that the recharge is characterized by significant spatial and temporal variability [5, 7, etc.]. Various techniques to quantify recharge are applied, depending on the purpose of the study, primary controlling factors, space and time scales, and available data [6].

The purpose of the study is to emphasize the capability of an easy-to-use method to estimate groundwater recharge for water-resource assessment based on meteo-data, to apply it to study sites in Bulgaria and to evaluate the efficiency of the method.

DESCRIPTION OF THE STUDY SITES

The study sites are from western and southern parts of Bulgaria (Fig. 1). The climate is temperate, with influence of the Mediterranean climate. Seasonality is well expressed, and the driest season is summer. Scarce rainfalls limit the evapotranspiration value at the end of the growing seasons.

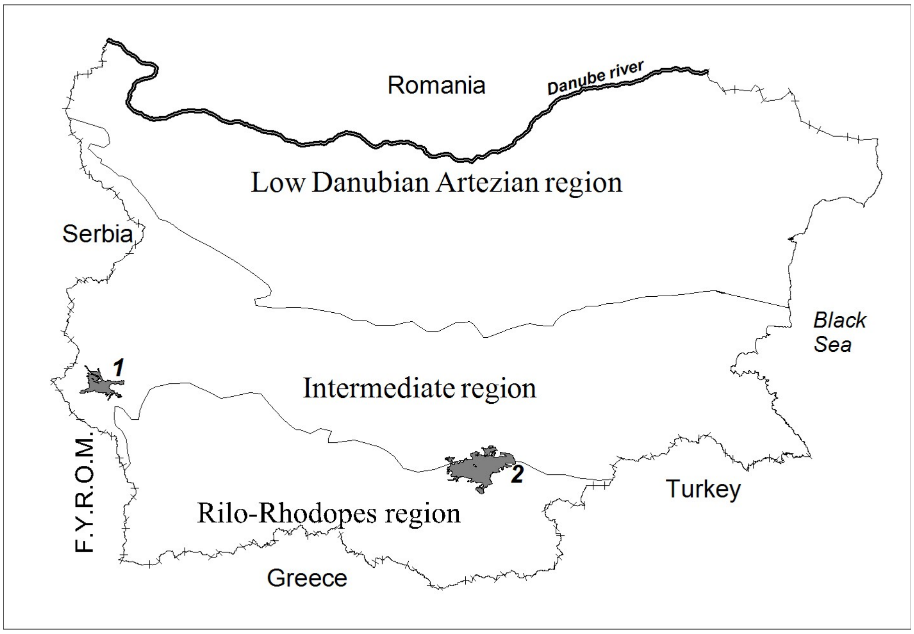

Fig. 1. Location of the study sites on the map of the major hydrogeological units of Bulgaria

The study site N 1 is located in western part of the country. This is Kyustendil Valley with synoptic station at the town of Kyustendil (42°16′ N, 22°43′ E, altitude 520 m asl). Mean annual precipitation total was 624 mm [8], and mean annual air temperature was 11.2˚C with the coldest month January (-0.8˚C) and the hottest – July (21.8˚C) [9].

The Kyustendil Valley is bounded by mountains. From tectonic point of view this is the Kyustendil graben filled in with Neogene-Quaternary fluvio-lacustrine deposits: mainly sand, sandstone, clay, lignite coal seams, limestone and diatomite of the Formations (from top to bottom): Tavalichevo, Koilitsa, Skrinyano, and Spasovitsa [10].

The Struma River is the main watercourse in the region. Fluvisols occupy the bottom of the valley along the Struma River and its tributaries and are the most widespread soil type in the area. The Chromic Luvisols cover peripheral parts of the valley and its slopes. Agricultural land use prevails in the valley, whereas forests cover the mountains. The estimated groundwater resources for the porous aquifer within of the Kyustendil

Valley are 490-500 l/s for the area of 165 km^2 covered by the Quaternary alluvial sediments [11]. The respective value of the specific groundwater discharge is 3 $l/s/km^2$.

The study site N 2 is located in southern part of Bulgaria, within the Upper Thracian Plain, south to the Maritza River. This is the Haskovo Valley with climatic station N 43010 (41° 57' N, 25° 34' E, altitude 230 m asl) at the town of Haskovo. Mean annual precipitation total was 667 mm [8], and mean annual air temperature was 12.5˚C with the coldest month January (0.2˚C) and the hottest – July (23.6˚C) [9].

According to the tectonic scheme of Bulgaria [12], the study area is a part of the East Srednogorie unit. Neogene fluvial-lacustrine sediments of the Ahmatovska Formation (ahN_{1-2}) are widely exposed in the area. They are presented by an alternation of sandy and clayey layers [11]. The Quaternary alluvial sediments follow the Haskovska River. The Chromic Luvisols are the main bioclimatic soil type for South Bulgaria, developed usually on Pliocene and early-Quaternary relief.

METHODS AND DATA BASE

The water-budget methods are widely applied to evaluate groundwater recharge [6, 13-15]. The use of a soil moisture balance method requires meteorological information and soil data, and common time steps are daily or monthly. The recharge is obtained as a residual of the water-budget elements that should be measured or estimated.

In this study, the program WATBUG [16] was used that provides computation of the climatic water budget. The required input is minimal: air temperature, precipitation and a few initial parameters. Latitude of the study site and the soil water holding capacity should be specified. The potential evapotranspiration (Eo) is defined according to the method of Thornthwaite, and the water budget can be computed on a monthly or daily basis using a classical equation of water balance for deep groundwater table:

$$dS/dt = P - E - R, \qquad (1)$$

where S is the soil moisture storage, dS/dt is rate change of the soil moisture storage, E is actual evapotranspiration, R is water surplus or total runoff. The program fulfils consecutive water balance for a single soil layer model. As a result, it provides such important water budget elements as the soil moisture storage, actual evapotranspiration and water surplus, which is interpreted as a groundwater recharge.

The program does not require detailed knowledge of the vegetation cover and soil characteristics. Moreover, the algorithm does not define surface runoff “as such functions are numerous and site specific” [16]. Comprehensive description of the soil moisture balance method and the program WATBUG can be found in many paper and reports [14-16, etc]. In the present study, the software code WATBUG_MVC provided by M. Van Camp was applied, who has made some corrections to improve the original code (personal communication).

For the purpose of the study, time-series from meteorological network are used that are in operation at the National Institute of Meteorology and Hydrology at Bulgarian Academy of Sciences (NIMH-BAS). The period 2000-2005 is investigated, and the time-series are provided in the frames of the JICA report [17]. This short period includes both dry and wet years. The soil water holding capacity of the topsoil layer is characterized by the parameter AWC (available water capacity), which for the Kyustendil Valley was set to 150 mm – a typical value for agricultural lands in

Bulgaria. For the Haskovo Valley, the AWC was set to 200 mm taking into account large thickness of the topsoil and its high water holding capacity [18].

RESULTS AND DISCUSSION

The program WATBUG was applied to quantify groundwater recharge for the study sites. The program was run for the period 2000-2005, using both daily and monthly meteo-data.

For the Kyustendil Valley, the input data included air temperature from synoptic station Kyustendil and precipitation (from precipitation stations NN 62525 – Tavalichevo, 62510 – Nevestino, and 62440 – Dragovishtitsa). The obtained results according with the input data are presented in Table 1 and Fig. 2. In Table 1 Sav means mean annual soil moisture storage.

Table 1. Calculated mean annual water budget for Kyustendil (the period 2000-2005) for AWC = 150 mm

Budget element	62510 - daily	62440 - daily	62525 - daily	62525 - monthly
P, mm	533.4	544.2	559.1	559.1
Eo, mm	713.0	713.0	713.0	692.0
E, mm	426.8	451.7	432.2	484.3
Sav, mm	53.4	51.6	100.3	87.0
Sav / AWC	0.356	0.344	0.669	0.580
R, mm	106.8	92.8	126.8	75.2
R/P, %	20.0	17.1	22.7	13.4

Mean annual air temperature during the investigated period (2000-2005) was 11.4˚C, and the mean annual precipitation totals raged from 530 to 560 mm (see Table 1). These values are close to their climatic averages. Mean annual recharge for the period 2000-2005 was 127 mm/y (N 62525), i.e. 22.7 % of the total precipitation sum for the same period. The recharge rate varied considerably in relation to rainfall conditions.

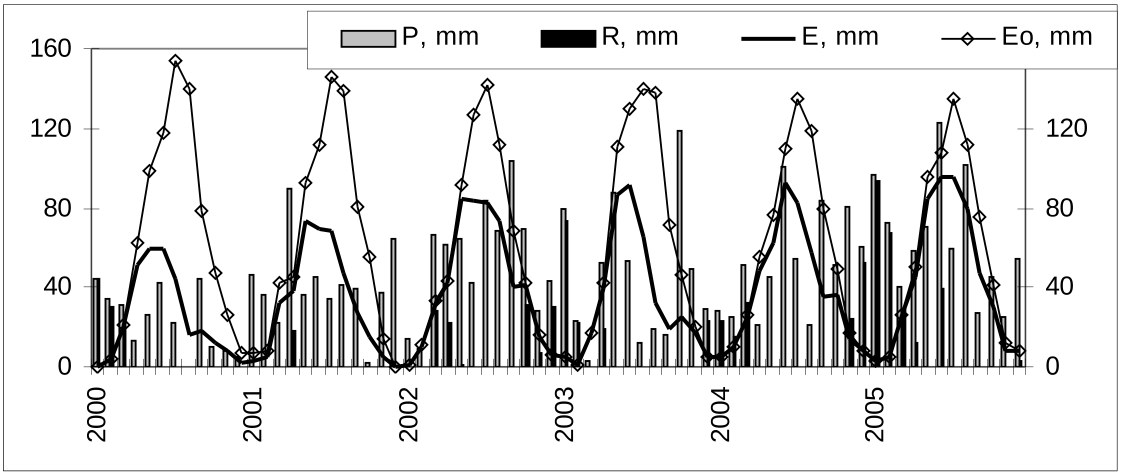

Fig. 2. Calculated monthly water budget elements for the Kyustendil Valley (station N 62525, daily data) for AWC = 150 mm

The time-series of the monthly water budget elements including recharge rates and soil water reserves for the study period are presented in Figures 2 and 3 (for station N 62525, using daily data).

It is evident from Fig. 1 that the actual evapotranspiration is limited by the water availability. Furthermore, the soil moisture reserves are very low in 2000 and 2001, which corresponds to the registered severe soil drought in summer months of these two years [19]. The highest monthly recharge rate (94 mm) was obtained for January 2005 (see Figures 2 and 3) in respect to heavy rainfalls (96.9 mm) mostly in the end of the month concomitant with fully saturated soils.

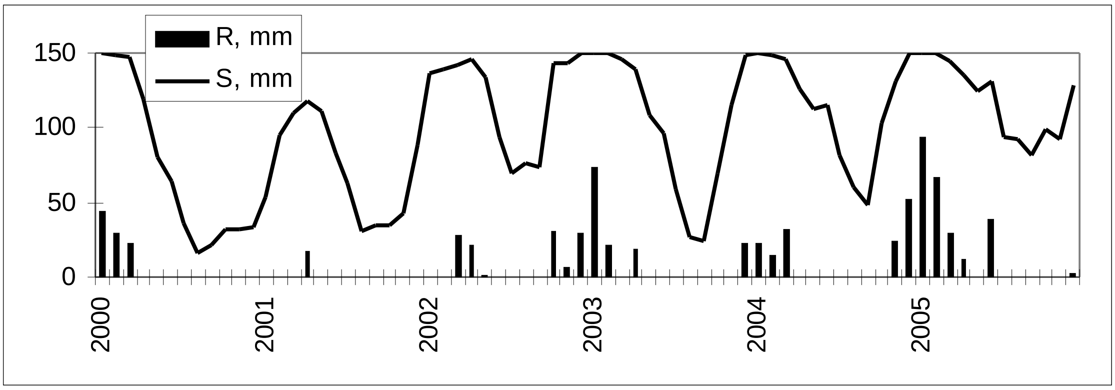

Fig. 3. Calculated monthly recharge rates and soil water reserves for the Kyustendil Valley (station N 62525, daily data) for AWC = 150 mm

The results from the daily input data provide reliable estimates for the recharge variability for the period 2000-2005 in respect to changes in precipitation and air temperature. Typically, the recharge occurs at the end of the dormant season when the evaporative demand is low, and the soil is saturated.

Comparison of the results from daily and monthly input data shows that using monthly meteo-data leads to underestimation of the obtained recharge values, as Dr. Van Camp has noted (personal communication). Daily data are necessary to obtain reliable estimates of the groundwater recharge based on the soil moisture budget model.

Table 2. Calculated mean annual water budget for Haskovo (the period 2000-2005) for AWC = 200 mm

Budget element	43402 - daily	43490 - daily	43410 - daily	43410 - monthly
P, mm	658.6	617.6	606.4	606.4
Eo, mm	780.5	780.5	780.5	755.3
E, mm	497.7	447.8	451.2	512.0
Sav, mm	138.7	131.3	129.8	113.9
Sav / AWC	0.925	0.875	0.865	0.569
R, mm	161.2	169.8	155.3	94.5
R/P, %	24.5	27.5	25.6	15.6

The input data from the Haskovo Valley included air temperature from climatic station Haskovo and precipitation (from precipitation stations NN 43402 – Dimitrovgrad, 43410 – Mineralni bani, and 43490 – Konush). The obtained results according with the input data are presented in Table 2 and Figures 4 and 5. Mean annual air temperature during the investigated period (2000-2005) was 12.8˚C, and the mean annual precipitation totals raged from 606 to 660 mm (see Table 2). These values are close to their climatic averages.

The obtained results are similar to the first study site. The years 2000 and 2001 were dry, and the year 2005 very wet. As a result, both the soil moisture reserves and the groundwater recharge were low in the beginning of the studied period. Abundant precipitation in 2005 had resulted in wet topsoil and high recharge rate.

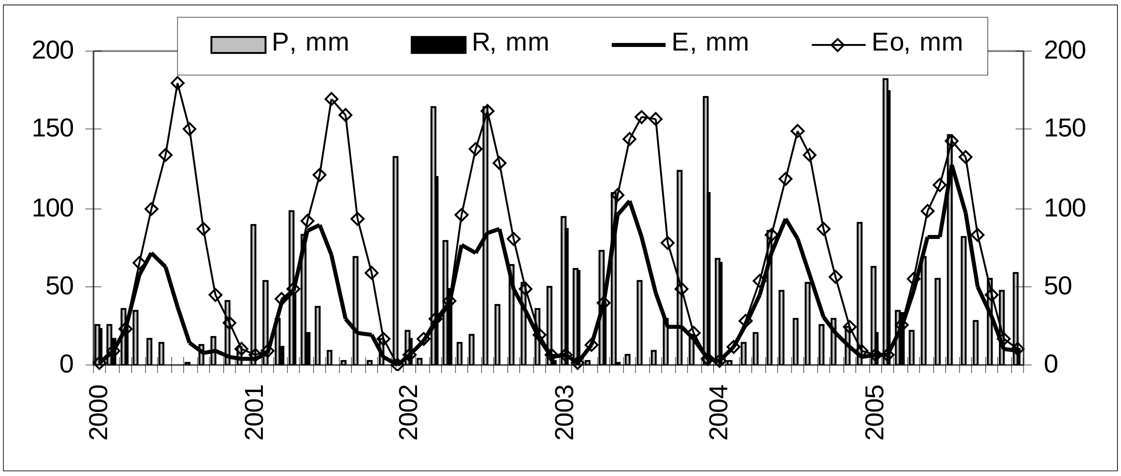

Fig. 4. Calculated monthly water budget elements for the Haskovo Valley (station N 43410, daily data) for AWC = 200 mm

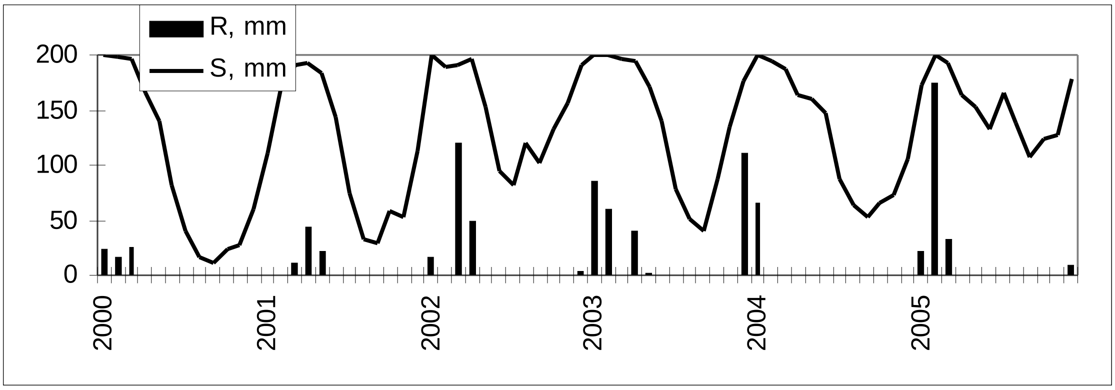

Fig. 5. Calculated monthly recharge rates and soil water reserves for the Haskovo Valley (station N 43410, daily data) for AWC = 200 mm

In general, good saturation of the soil layer, which occurs mostly after snowmelt or heavy rainfalls (as in early 2005), is an important factor in the onset of the recharge. The presence of vegetation switches the water balance towards higher evapotranspiration.

CONCLUSION

Evaluation of the recharge rate is important for various applications related to water management. The soil moisture balance model provides allocation of the precipitation into the soil moisture storage, evapotranspiration and recharge based on meteo-data.

The program WATBUG based on a soil moisture balance model was used to quantify groundwater recharge for the two study sites: the Kyustendil Valley (western Bulgaria) and the Haskovo Valley (southern Bulgaria). The obtained results have proven substantial temporal variability of the groundwater recharge mostly as a result of the large temporal variability in precipitation. The period 2000-2005 was used, which includes both dry and wet years. The recharge rate was low in 2000 and 2001 in respect to scarce rainfalls in most parts of the country. Severe soil drought in summer months of these two years was registered, proven by the depleted soil water reserves.

The applied approach is important when data on groundwater is lacking or where they are influenced by human activity, as in many regions of the country. The method provides time-series of the different budget elements including groundwater recharge. Daily data are necessary to obtain reliable estimates of the groundwater recharge based on the soil moisture budget model.

Using long historical time-series of the air temperature and precipitation would allow understanding the long-term variability of the groundwater recharge, which is important for the groundwater resources management.

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