CLIMATE VARIABILITY AND GROUNDWATER RECHARGE: CASE STUDY OF WATER BALANCE FOR THE CENTRAL NORTH BULGARIA

Tatiana Orehova, Tanya Vasileva

Geological Institute – BAS
24, "Acad. G. Bonchev" Str., 1113, Sofia, Bulgaria

tvorehova@gmail.com; tmv75@abv.bg

Abstract

Temporal variability of the groundwater recharge was evaluated for a study area situated in the Central North part of Bulgaria. For the purposes of the study, a simple model was developed in Excel that produces the partitioning of the rainfall amount (on monthly basis) between evapotranspiration and groundwater recharge. Both multi-annual value of groundwater recharge and its variability were evaluated for the period 1977-2004. Impact of the water shortage on the groundwater recharge and spring runoff was studied. It was found that winter drought has a direct adverse impact on the recharge. Significant correlation was obtained between the mean annual spring discharge and the calculated groundwater recharge.

Keywords: water balance, drought, groundwater recharge, soil moisture

Introduction

The impact of climate change on groundwater has become very actual theme since the end of the last century. Large variability in precipitation sums has been registered in Bulgaria during the last decade. Drought periods have become rather frequent, and the water balance elements showed large deviations from their multi-annual values (Benderev et al., 2008).

In this study, the impact of the droughts is considered in the context of the changes in the water budget. The water balance elements for the period 1977-2004 are evaluated based on a water balance model (on monthly basis) for a study area in Central Bulgaria.

This method in different modifications has been used for decades (Xiong et al., 1999). The specific features of the different variants are related to the definite climatic conditions. For example, for wet climate a method with two parameters was successfully tested for 70 watersheds in China (Xiong et al., 1999). For the climatic conditions of Bulgaria, this modification is not applicable as evapotranspiration at the end of growing seasons is restricted by the soil moisture availability. Another specific feature of the study area is important seasonal fluctuation of the soil moisture content, according to agrometeorological observations.

This simple method has been used for evaluation of the groundwater recharge (Finch, 1998) as well as for estimation of its changes related to the climate variability (Gómez et al., 2010).

This paper presents a modification of the method suitable for conditions in Bulgaria. It allows partitioning of water between recharge and evapotranspiration. The method was applied for a study area in the Central North Bulgaria. Variability in the time-series (precipitation sums and spring discharge) was studied for the period 1977-2004.

Methods and data

For the purposes of the study, a simple model was developed. It produces the partitioning of the rainfall amount between evapotranspiration and groundwater recharge. The input data are monthly sums of rainfall (P) and of potential evapotranspiration (PE), which is evaluated using the method of Thorntwaite (1948) based on mean monthly air temperatures typical for the study area.

A classical equation of water balance is as follows (Peixoto and Oort, 1992):

$$dS/dt = P - E - R_t, \tag{1}$$

where S is soil moisture content, dS/dt is rate of storage of water, E is actual evapotranspiration, R_t is surface and subterranean runoff. This equation is applicable for deep groundwater table.

One important parameter is the available water capacity of the soil $S_{\max}$. Available water capacity is the maximum amount of plant available water, which a soil can provide. Seasonal fluctuations of the soil moisture content are typical for the temperate climate. This fact is confirmed by long-term observation on agrometeorological stations in Bulgaria.

At first, the difference $P - PE$ is calculated. If the difference is positive, the actual evapotranspiration is equal to PE, and the rest water goes to replenish the soil moisture content. If this difference is negative, the evapotranspiration is restricted by availability of the moisture, and it is equal to the precipitation amount ($E = P$). The soil moisture in excess to $S_{\max}$ goes to the groundwater recharge (R).

Under negative difference ($P - PE$), which is frequent case during the growing seasons, the soil reserves diminish according to the exponential function. This moisture is used for evapotranspiration. In this case, no groundwater recharge occurs, and the soil moisture content decreases according to equation (Alley, 1984):

$$S_i = S_{i-1} \exp((P - PE)/S_{\max}), \tag{2}$$

where S_i and S_{i-1} are soil moisture content of the current and the previous months respectively.

The study area is situated in the Central North part of Bulgaria. The climate is temperate, sub-humid. Seasonality is well expressed. The mean average precipitation amount for the meteo-station Veliko Tarnovo is 680 mm (Koleva et al., 1990). Monthly data for precipitation and air temperature were used for the period 1977-2004. Potential evapotranspiration was evaluated using the method of Thorntwaite. All mean yearly values refer to hydrological years (that starts on 1 October).

Observation station at the village of Musina was chosen for this study (station N 396 from the National Hydrogeological Network). This is a karst spring situated within the Yantra River Basin that appears at elevation 191.7 m above sea level. In this region, precipitation is the main source for groundwater recharge. Due to carbonate terrain, there is no surface runoff. The spring drains the Lower Cretaceous **limestone** with average discharge about 400 l/s. It shows high variability through years in respect to the climatic conditions.

Results and discussion

The described model (on monthly basis) was applied for the study area in the Central North part of Bulgaria. For the available water capacity of the topsoil, the value of 120 mm was adopted. The calculated yearly water balance for the station Veliko Tarnovo is presented on Fig. 1. The rainfall amount is partitioned between evapotranspiration, groundwater recharge and change in the soil moisture storage.

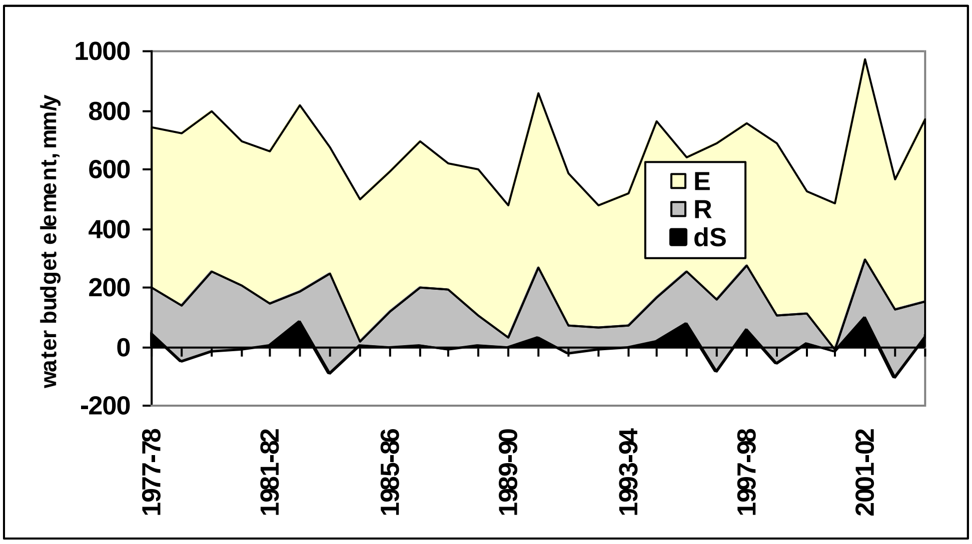

Fig. 1. Calculated partitioning of the annual precipitation sum between groundwater recharge and evapotranspiration for the period 1977-2004

The correlation between the mean annual spring discharge and the calculated groundwater recharge is significant (r = 0.72) – see Fig. 2. A noteworthy fact is that there is no correlation between the yearly precipitation sum and the mean annual recharge.

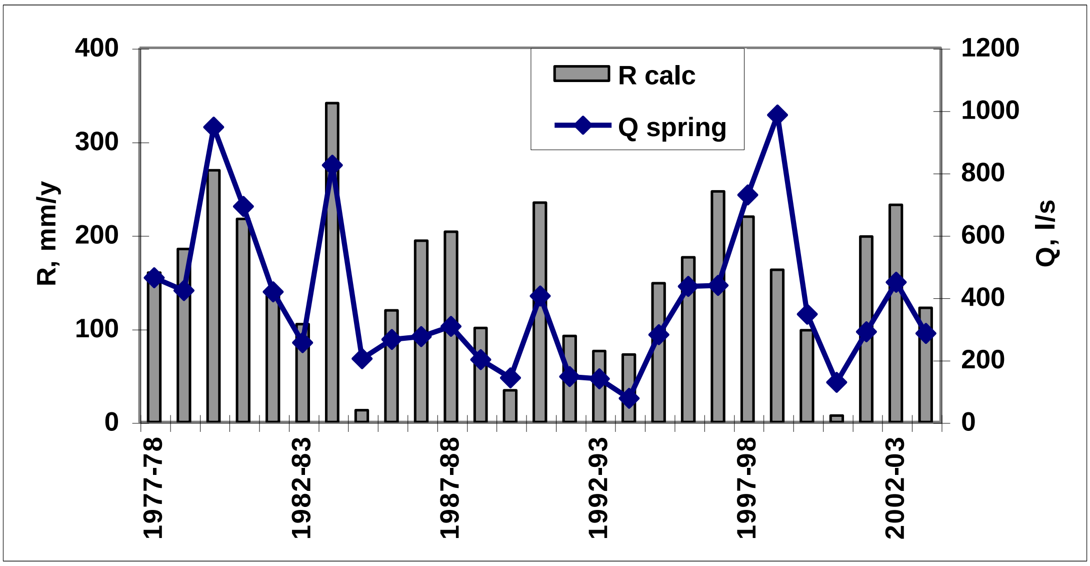

Fig. 2. Annual time-series of the calculated recharge and observed spring discharge

According to the model, the multi-annual value of the recharge is 154 mm per year, which is 23.3 % of the mean precipitation sum for the same period. The obtained value is consistent with the available groundwater resources map.

The groundwater is recharged mainly during the cold period from November to March. This process starts when the soil moisture content becomes near to its capacity. Yet, important difference was registered for particular years (Fig. 3).

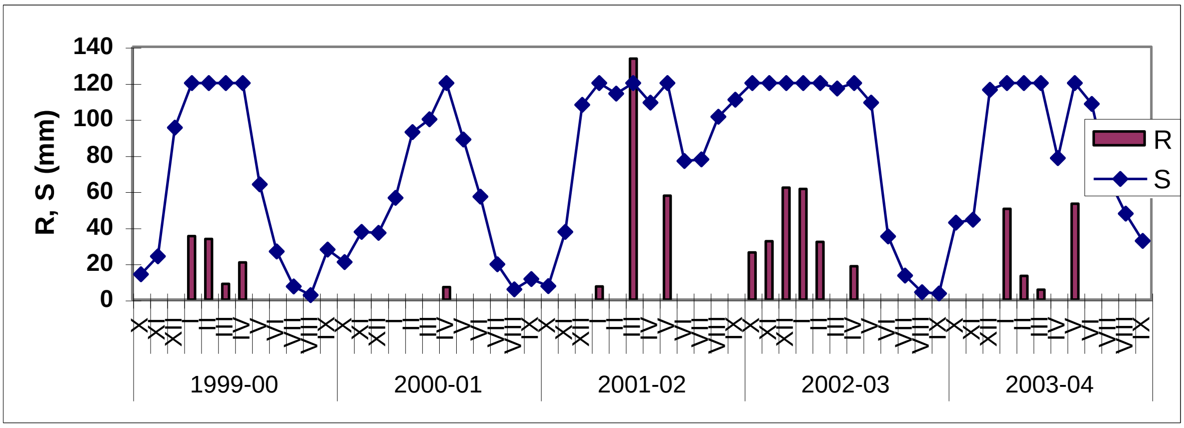

Fig. 3. Calculated recharge and soil moisture content for the period 1999-2004

Thus, the two consecutive hydrological years (1999-2000 and 2000-2001) show important difference in the water balance. The difference between precipitation sum for the second and the first year is only 42 mm. For the cold period (from October to March) this difference was as high as 103 mm (Fig. 4). Indeed, impact of the water shortage depends on the season. Summer droughts have direct adverse effect on crops. Winter droughts result in the smaller soil moisture reserves and lower groundwater recharge.

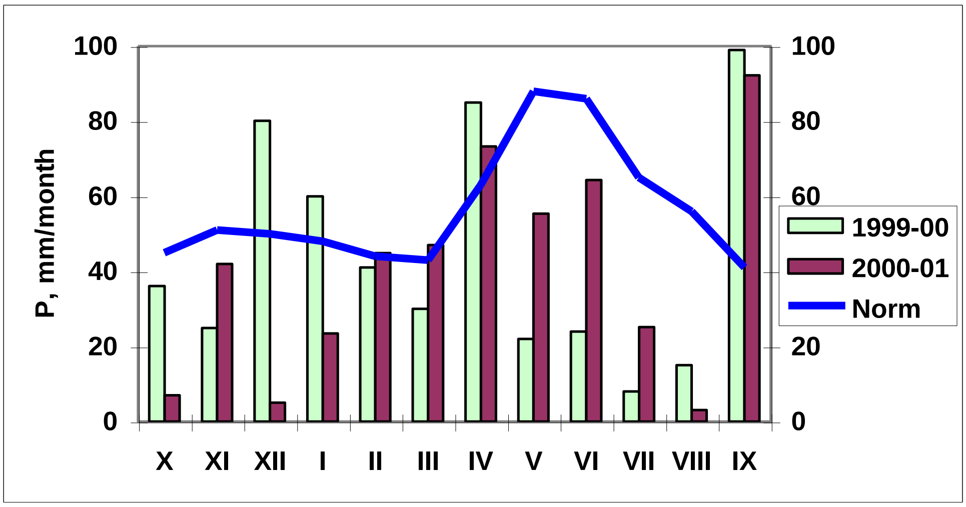

Fig. 4. Monthly precipitation for the selected periods

Actually, summer droughts result in decline of the actual evapotranspiration and consequently to lower crop yields. This is the case of the summer months of the year 2000. At the end of July 2000, an important reduction of the soil moisture content was registered – below 63% of the field capacity for the study area (Monthly Bulletin, July 2000).

For the same two years, monthly time-series of the spring discharge are presented on Fig. 5. It reveals low values of the spring discharge during the growing seasons for the same two hydrological years.

All the hydrological year 2000-2001 was very dry. As a result, very low values of spring discharge were registered. The model showed low groundwater recharge – one of the lowest according with 1984-85 (see Fig. 1 and 2). Generally, winter droughts result in reduced groundwater recharge.

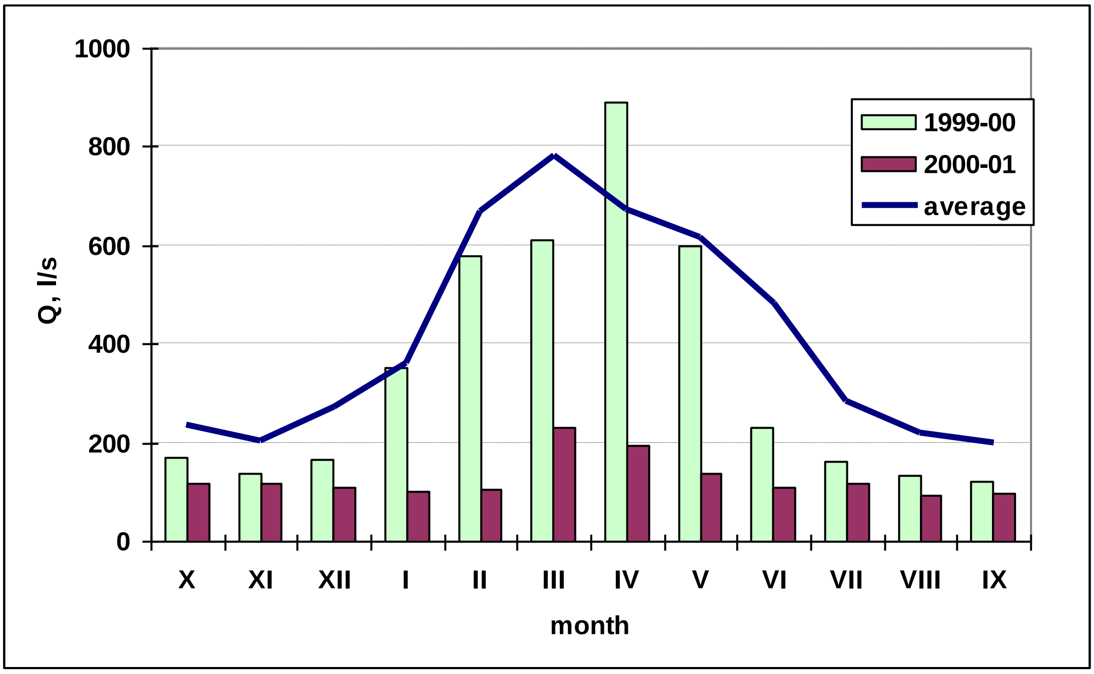

Fig. 5. Monthly spring discharge (N 396) for the selected periods

Conclusions

The present study concerns evaluation of the renewable groundwater resources along with their temporal variability. For the purposes of the study, a model was used that allows partitioning of the rainfall amount between evapotranspiration and groundwater recharge. Seasonal fluctuation of the soil moisture content is typical for the temperate climate and for that reason was taken into account in the model.

The typical features of the water balance for the study area are presented according with temporal variability of the hydrological components. Groundwater recharge shows high variability through years. The obtained multi-annual average was found (154 mm/y), which is consistent with the previously evaluated value. Significant correlation was obtained between the mean annual spring discharge and the calculated groundwater recharge, and no correlation with the mean precipitation sum.

The study showed difference in water shortage in cold and growing seasons. Summer droughts have direct adverse effect on the crops. Winter droughts result in smaller soil moisture reserves and lower groundwater recharge.

The results of the study could be used from the water management authorities.

References

Alley, W.M. (1984): On the treatment of evapotranspiration, soil moisture accounting, and aquifer recharge in monthly water balance models. *Water Resour. Res.* **20**, (8), 1137-1149.

Benderev, A. D., T. V. Orehova, E. K. Bojilova (2008): Some aspects of groundwater regime in Bulgaria with respect to climate variability. In: Geological Society, London, Special Publications; v. 288, p. 13-24.

Gómez, A., L. B. Rodríguez, L. S. Vives (2010): The Guarani Aquifer System: estimation of recharge along the Uruguay–Brazil border. *Hydrogeology Journal*, Vol. 18: 1667-1684.

Koleva E., Peneva R. (1990): *Climatic reference book. Precipitation in Bulgaria.* Sofia: Bulgarian Academy of Sciences Press, 169 pp. (in Bulgarian).

Monthly Bulletin, July 2000 (2000): National Institute of Meteorology and Hydrology – BAS (in Bulgarian) http://www.meteo.bg

Peixoto, J.P., A. H. Oort (1992): Physics of climate. Springer, 520 p.

Xiong, L., S. Guo (1999): A two-parameter monthly water balance model and its application. *J. Hydrol*. 216, 111–123.