Evaluation of groundwater recharge to the transboundary aquifer along the Maritsa River

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ABSTRACT

Transboundary aquifer along the Maritsa River is shared between Bulgaria, Greece and Turkey. Specific features of the multiannual water balance for the lower reach of the Maritsa River within Bulgarian territory are described. This is water balance *in situ* on entry into the groundwater system. Seasonality is well expressed, and the water budget elements are evaluated on monthly basis. Soil moisture variability is a weighty element of the water balance in the study area. Shallow aquifer is important in maintaining the high summer evaporation rate. The regional groundwater recharge is about 25% from the mean yearly precipitation sum, but occurs mainly during non-growing season. In general, water balance studies in the area are necessary on regular basis.

Key words: transboundary aquifer, water balance, soil moisture, shallow groundwater, the Maritsa River

1. INTRODUCTION

Transboundary issues related to water resources are important for Bulgaria. The rivers Struma, Mesta, Maritsa and Tundja are crossing the southern border of the country. Aquifers associated to these transboundary rivers in their low reaches are shared between Bulgaria and its neighbour countries – Greece and Turkey. Nowadays the International Law of Transboundary Aquifers is in preparation. Draft Articles on the law are adopted. National information on transboundary aquifers should be shared between neighbour countries to avoid conflicts and to facilitate cooperation and management of the shared groundwater resources.

Along the low reach of the Maritsa River, a transboundary aquifer shared between Bulgaria, Greece and Turkey is identified. This is alluvial aquifer EB56 (Svilegrad /Stambolo /Orestiada), according to the Transboundary Aquifers Inventory in South-Eastern Europe (Puri and Aureli, 2009). The study region located in Southeastern part of the country coincides with the area covered by the transboundary aquifer within its Bulgarian territory.

The aim of the study is to clarify specific features of the water balance within the study area. A special attention is given to evaluation of the groundwater recharge.

2. GENERAL DESCRIPTION OF THE STUDY AREA

2.1. Climate, topography and hydrology

The climate for the study area is temperate, influenced by Mediterranean climate. Rainfall sums are about 550-600 mm yearly (Koleva and Peneva, 1990). Seasonality is well expressed, and the driest season is summer. Scarce rainfalls limit the evapotranspiration value at the end of the growing seasons.

The Maritsa River is the main watercourse in the region. According to data from the river gauge at Svilengrad, it is 180-230 m wide depending on the water stage. The width of the river valley near the state boundary is about 4-5 km. The slope of the riverbed is rather low – 0.23 per mille (General Master Plans, 2000). The amplitude of variation in water stage is about 2 m. High water stages are associated to high flow rates usual for spring months. Floods occur generally in cold part of the year.

Artinian *et al.* (2008) realized a coupled hydrometeorological model of the Maritsa basin incorporating unsaturated flow reservoirs.

2.2. Geological and hydrogeological settings

According to the tectonic scheme of Bulgaria (Dabovski *et al.*, 2002), the study area is a part of the East Srednogorie unit. The Tertiary deposits comprise Eocene-Oligocene and Neogene continental to shallow marine clastics and carbonate rocks. Neogene fluvial-lacustrine sediments of the Ahmatovska Formation (ahN_{1-2}) are fine-textured and present an alternation of sandy and clayey layers. The thickness of this formation varies from 50 to 280 m (General Master Plans, 2000). Neogene deposits are widely exposed in the area. Groundwater collectors are related to layers from coarse-grained materials (gravel and sand). Quaternary deposits in the study area are represented mainly by alluvium of the Maritsa River and its tributaries (sand and gravel with thin layers of silt and clay) with thickness up to 22 m.

Groundwater in alluvial and Neogene sediments shows different chemical characteristics and total dissolved solids. Both aquifers are considered as a unique aquiferous system with high transmissivity about 1000 m^2/d, and groundwater resources of 350 l/s for the area of about 160 km^2. The TDS content in groundwater varies in the range from 0.39 to 0.89 g/l (General Master Plans, 2000).

Warmer groundwater temperature (in the range 14-15ºC) for some wells testifies to mixing of groundwater from the alluvial and Neogene aquifers. In general, mixed groundwater has a specific chemical composition.

The groundwater flow is drained by the Maritsa River and its tributaries. Water stages in the Maritsa River are of primary importance for its water exchange with the aquifer system. Low water stages (generally in late summer and early autumn) favour groundwater discharge. The low flow of the right tributaries of the Maritsa River (Biserska and Lozenska Rivers) is maintained by groundwater of the Neogene aquifer (Antonov and Danchev, 1980).

Numerous faults marked on the geological map (both proven and supposed) are expected to facilitate considerably the mixing and local drainage power of the aquifers (especially for the deeper Neogene aquifer) in the respective reach.

2.3. Soil and land use

Cinnamonic forest soils are the main bioclimatic soil type for South Bulgaria, developed usually on Pliocene and early-Quaternary relief (Koinov et al., 1998). In the study area, they are leached. Rankers are shallow soils related to silica-reach rocks under erosion, and Rankers with cinnamonic forest soils are widely developed in the area. Fluvisols are intrazonal soils that are genetically related to the alluvial deposits in the river valley. Other soil variety is Planosols.

In respect to the general climate features, the agricultural activity in the region is effective under irrigation. The sources of irrigation in the study are local reservoirs and the river.

3. OBJECTIVES, METHODS AND DATA

The objective of the study is to characterize general features of the water balance of the area with special attention to the groundwater recharge formation. The water balance is considered on monthly basis with data from the study area. A multiannual average water balance is presented.

The method of Thorntwaite was used to calculate the potential the evapotranspiration (PE). In agrometeorological practice, FAO recommends using of reference evapotranspiration ETo (Allen et al., 1998), based on daily meteorological data.

The main method used in the study is the water budget equation on monthly basis.

In general, the role of the soil moisture variability in the water balance is the most important for temperate climate, where the soil moisture varies from wilting point up to field capacity throughout the year (Lawrence et al., 2007). Heterogeneity of topography and the depth to the groundwater table control the spatial variability of the soil moisture content. The hydraulic conductivity of the unsaturated soils strongly increases with enhanced soil moisture content. As a result, wetter lands receive more groundwater recharge.

In relation to difference in the interannual rainfall distribution, two types of water balance are identified – for temperate and for Mediterranean climate (Laio *et al.*, 2002). Limited area of the country is a prerequisite for mixing of the two main types of the precipitation regime (Mateeva, 2002). Such effect was registered by Artinyan et al. (2008) who reported rather different distribution of rainfalls in two successive years, typical for different climates.

In Bulgaria, a network of agrometeorological stations is in operation, and up to now near 50-year time-series is available at the National Institute of Meteorology and Hydrology at Bulgarian Academy of Sciences (NIMH-BAS). Long-term agrometeorological observations in Bulgaria (Slavov and Georgieva, 2001) show that soil moisture varies in wide range throughout the year. Generally, by the end of each growing season the soil moisture in the topsoil is low. It increases steadily during cold season, reaching maximal values (about field capacity) in March. Since the onset of new growing season, water reserves in soil gradually decrease. The most severe reduction of the soil moisture content occurs in June and July according to high demand of plants in water. Then the soil moisture may reach the wilting point value.

The groundwater recharge is a part of the water balance of the area. The large-scale water balance equation can be written in relation to changes in the soil moisture content as (Yeh and Famiglietti, 2009):

$$\frac{dW}{dt} = P - E - R_S - R\,, \tag{1}$$

where W is soil moisture content, t is time, P is precipitation; E is evapotranspiration; Rs is surface runoff; and R is percolation to the water table. Deep percolation becomes recharge of the shallow groundwater. All the variables in Eq. (1) represent the regional-scale spatial averages on monthly basis.

The water balance equation for an unconfined aquifer can be written as:

$$S_y \frac{dH}{dt} = R - R_b\,, \tag{2}$$

where Sy is the specific yield of the unconfined aquifer; H is the groundwater level; R is groundwater recharge ; and Rb is groundwater runoff (base flow).

Data consist of precipitation sums, monthly dataset on soil moisture, and water table depth. Monthly data on precipitation are from multiannual averages for the station Svilengrad. The hydrogeological time-series refer to groundwater table for the observational well N 531A at Biser village, average values for the 1981-1988 period. The precipitation at the station Kardjali from Southern Bulgaria for this period shows monthly sums close to their norms (multiannual average). In general, both restricted data availability and the lack of free access to data impeded the work.

4. RESULTS AND DISCUSSION

The annual average precipitation at the station Svilengrad is 595 mm (Koleva and Peneva, 1990). The potential evapotranspiration is evaluated using the method of Thorntwaite based on monthly average air temperatures.

The reference evapotranspiration using the FAO Penman-Monteith method (Allen et al., 1998) was calculated for all agricultural regions of Bulgaria by Moteva et al. (2008) based on long-term (1971-2000) daily and monthly meteorological data. The obtained values refer to the potential vegetation period March-October. For the region of Svilengrad, the reference evapotranspiration is 830 mm (Moteva et al., 2008).

For in the study area, the soils moisture available for plants is assessed as 135-150 mm for all soil types except for Rankers that are shallow soils (Koinov et al., 1998). Data on the soil moisture content at the agrometeorological station Lubimets situated in the study area were used. According to data, water reserves in soil gradually decrease since the onset of new growing season. The depleted soil moisture is recovered on the account of precipitation sums during the cold season. The presented water balance studies are under natural conditions, and irrigation was not taken into account. The need of crops in water is partly due to contribution from groundwater and soil.

For the study area, average annual cycles of balance components are presented on monthly basis. Different aspects of the multiannual water balance are presented on Figures 1-3, and Table 1.

The alluvial aquifer is related to permeable layers of sand or gravel that are overlain by less permeable deposits. The specific yield of the shallow aquifer is defined as a difference between total porosity and field capacity. For most of the soil textures typical for Bulgaria, the values of specific yield ranges from 0.07 to 0.08. This analysis is made based on the parameters of Bulgarian soils, evaluated by Rousseva (2001, 2006). In the present study, the value of 0.08 was used for the specific yield of the alluvial aquifer.

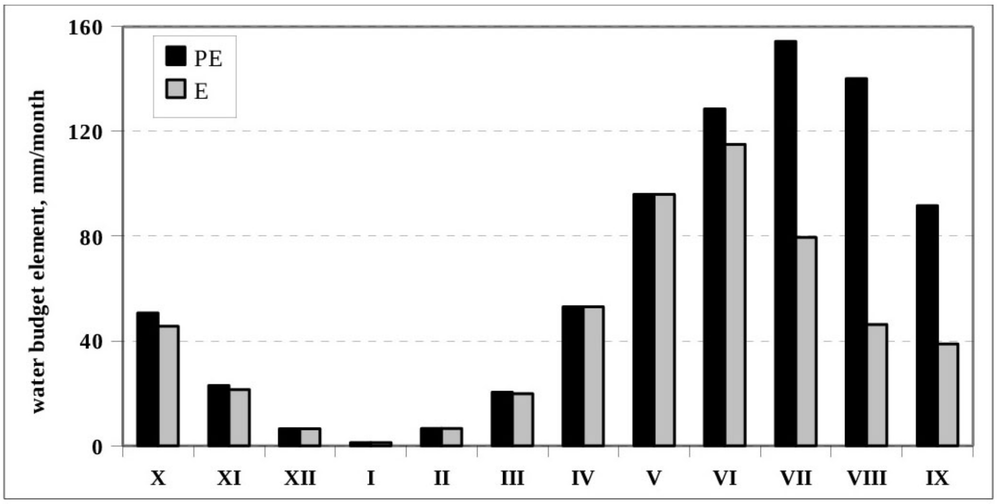

Figure 1. Multiannual average values of the potential (PE) and actual (E) evapotranspiration for the study area.

A typical feature of the water balance elements is their seasonality. The potential evapotranspiration has a maximum in July, and the actual evapotranspiration is limited by availability of water at the end of the growing season (Fig. 1).

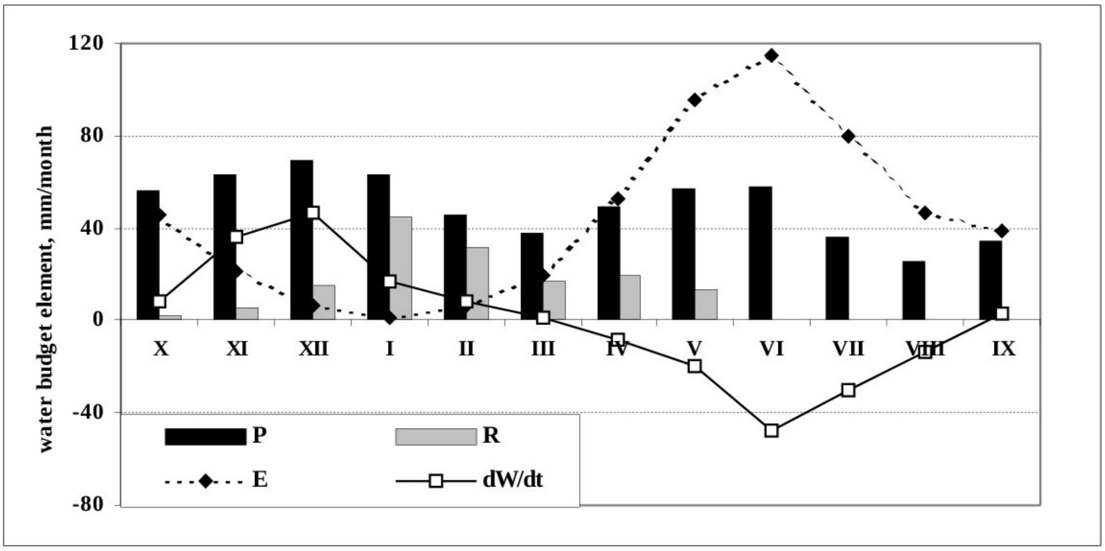

Figure 2. Interannual variability of the monthly precipitation sum (P), evapotranspiration (E), groundwater recharge (R), and soil moisture content (dW/dt).

The groundwater recharge occurs mainly during cold non-growing season. The groundwater recharge is split into storage into the shallow aquifer and the lateral outflow. The water reserves stored both in the topsoil and the shallow aquifer, are highly variable throughout the year (Fig. 2 and 3).

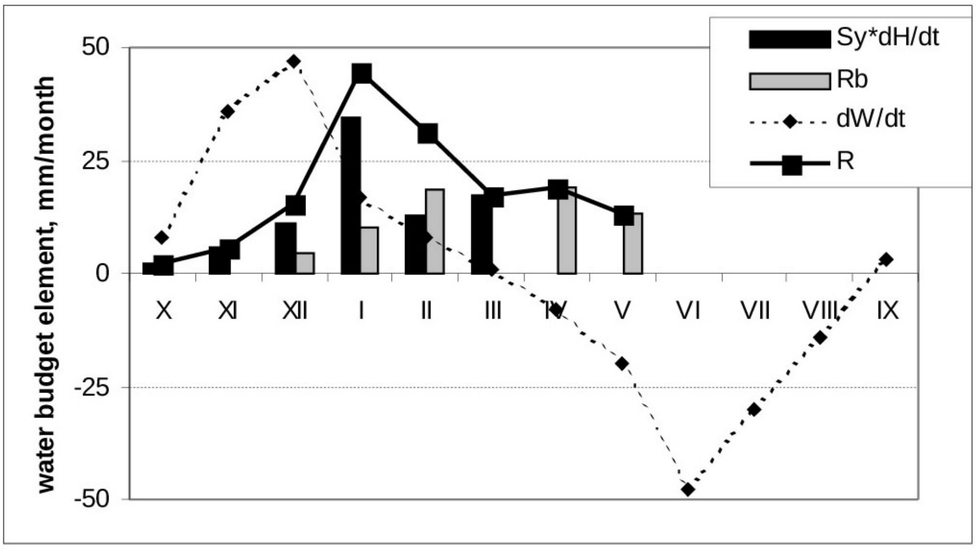

Figure 3. Interannual variability of the soil moisture content (dW/dt) and monthly groundwater recharge (R), including its components – water storage in aquifer (Sy*dH/dt) and baseflow (Rb).

The obtained value of the regional groundwater recharge (149.3 mm/an) is about 25% from the mean yearly precipitation sum (Table 1). This value is in consistence with the Groundwater Resource Map of Bulgaria (1979).

Table 1. Element of the yearly water balance in the study area

Element, index	Annual sum	Value	Sum for the period X-III
P, mm	595		335
PE, mm *	771.9		
PE / P (aridity index)		1.3	
E, mm	529.7		101.1
E / P		0.89	
Groundwater recharge R, mm	149.3		
including:			
- groundwater storage	84		
- lateral outflow (baseflow)	65.3		
R / P, %		25.1	

* - according to Thorntwaite

During summers, upward capillary flux from the shallow aquifer (exfiltration) occurs. Thus, the shallow aquifer is important in maintaining the high summer evaporation rate.

The groundwater recharge is controlled mainly by the precipitation sum during non-growing season, maximum soil water storage capacity and evaporation during the same period.

The presented water balance is typical for a multiannual period. In future, water balance studies are necessary on regular basis.

5. CONCLUSION

The transboundary aquifer along the Maritsa River is shared between Bulgaria, Greece and Turkey. General features of the terrestrial water balance in the study area are presented. This is water balance *in situ* on entry into the groundwater system, typical for multiannual period. Seasonality is well expressed. Evapotranspiration and soil moisture fluctuations are important balance elements, controlled by climate, soils and vegetation.

Regional groundwater recharge is estimated taking into account soil water balance computation. The soil moisture variability and evapotranspiration are important balance elements. The water budget elements are evaluated on monthly basis.

According to the water balance data, the groundwater is recharged mainly during non-growing season. The recharge value is about 150 mm annually, which is 25% of the yearly precipitation sum. The groundwater recharge is controlled mainly by the difference between precipitation and evaporation during the cold part of the year, and the maximum soil water storage capacity.

In general, water balance studies in the area are necessary on regular basis.

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