Groundwater In The Watershed Of Tundja River, Bulgaria

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Abstract

The paper gives a general view on groundwater for the watershed of the Tundja that is transboundary river. Several known cases of surface water – groundwater interaction are presented. Some specific aspects of groundwater regime are concerned.

For the purpose of implementation of the EU Water Framework Directive, groundwater bodies in Bulgaria have been delineated together with their initial characterization. Groundwater in porous, karst and fractured rock media is present within the watershed of the Tundja River.

The purpose of the paper is harmonization of a vast amount of data to obtain a better understanding of the aquifer systems for the watershed of the Tundja River. The study is accomplished at basin-scale. Such approach is useful for the water resources management, as the basin is considered as a unity.

Keywords: Tundja river basin, aquifers, groundwater bodies, Bulgaria

Introduction

Tundja is a transboundary river shared between Bulgaria and Turkey. The watershed of the river belongs to the East-Aegean Basin. Tundja is the largest affluent of the river Maritza that joins the main river within Turkish territory. The length of the river up to the state boundary is 350 km, and the corresponding watershed area - 7884 km^2.

According to the orographic characteristics, the watershed of the Tundja river could be separated into western, middle and southern parts. The upper part of the watershed is situated in the mountain region. River Tundja springs at 1940 m above mean sea level, east from the peak Botev, and flows from west to east between mountain chains: Stara Planina in the north and Sredna Gora in the south. In the middle part of the river before Yambol town an abrupt change in direction is observed, and the river flows between hills following south direction up to the state boundary with Turkey (Fig. 1).

The climate of the river basin is transitive between continental and Mediterranean types, with evident influence of the last type in its southern part. The annual precipitation totals are in the range 500 - 600 mm for the plain, increasing in high mountain part up to 1087 mm (multi-annual average value) for the peak Botev.

In Bulgaria a basin approach is accepted for the water management. It is realized that such approach ensures a real background to solve practical tasks related to waters within the river basin, taking into consideration very usual cases of groundwater- surface water interaction.

The objective of the paper is harmonization of vast amount of data on groundwater in the watershed of Tundja river. General description of groundwater at the basin scale based on available information is presented. Special attention is paid to interaction of aquifers with surface waters.

Groundwater in the Tundja river basin

General remarks

General description of groundwater in the Tundja river basin is done by Antonov and Danchev (1980). The up-dated information is given in General Master Plans (2000).

Highly productive in groundwater porous media are related to intermountain kettles filled in with Neogene-Quaternary deposits. The most important from them are: Kazanlak kettle in western part, Sliven-Straldja area in central part, and Yambol-Elhovo area in southern part of the basin (Antonov, 1980; General Master Plans, 2000). More details for Sliven-Straldja area (in central part) is given by Raikova (1973), and for Yambol-Elhovo area in southern part of the basin – by Raikova et al. (1974).

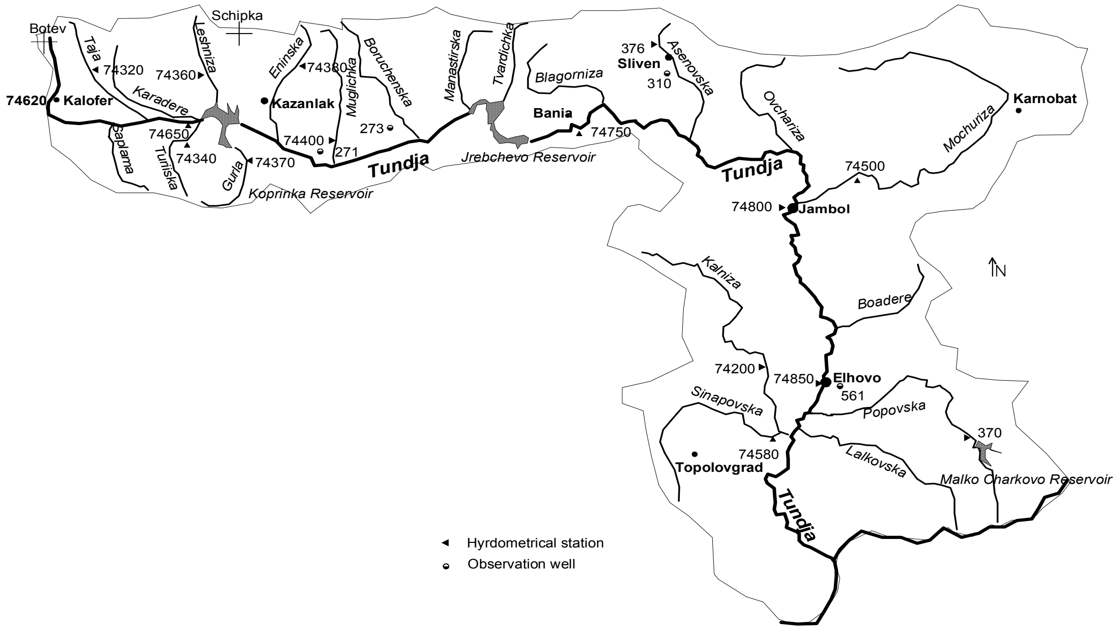

Figure 1. Tundja river basin

The characterization of the aquiferous sediments is essential for the purposes of hydrogeology. On the base of mapping and description of genetic types of Quaternary sediments in Sliven-Straldja area, Angelova (1992) recovered morpho-structural evolution of the depression. The map of isopachites of Quaternary deposits shows important localities with enhanced thickness, related to grabens or along the river. Similar work has been done by Angelova et al. (1991) for the Tundja depression in Yambol-Elhovo area. The isopachite map shows important increase of the Quaternary sediments along the main river body in several spots south from Yambol, north and south from Elhovo town.

The natural recharge of porous aquifers in the Tundja river basin is mainly by stream leakage, followed by rainfall infiltration. The main river and its tributaries traversing the river basins leak water to aquifers. On the other hand, streams gain flow from groundwater. In general groundwater-surface water exchanges are usual in this river basin and vary in space and in time. The recharge due to fissured water originating from surrounding environment of the porous aquifers is usually non-important with some exceptions (for example, Sungulare-Karnobat kettle).

The discharge of the aquifers occurs in the permanent river network through the base flow, as rivers represent the main discharge zones of the unconfined aquifers. Another way of groundwater discharge is through the evapotranspiration, or directly by evaporation. The last factors are the most manifested in areas with groundwater level close to the ground surface. Such are areas in the vicinity of the riverbed, floodplains or marshlands (Strandjansko marshland is now drained).

Construction of the dams considerably altered natural river-groundwater interactions. More evident consequences are raising of the water table upstream of the dam, causing some losing streams to become gaining streams, and lowers the water table downstream, causing gaining streams to become losing. Besides, before construction of the dams the river used to flood. Such flooding used to contribute to important regular recharge for the alluvial aquifers in the lower reaches.

Karst terrains usually generate large groundwater resources. Within the Tundja river basin, several karst massifs are identified: Maragidik, Shipka, Tvarditza–Sliven and Topolovgrad (Antonov et al., 1980; General Master Plans, 2000). The first of them is the richest in groundwater resources due to combination of high precipitation sums and karst terrain.

Wide range of the values of groundwater discharge given as a result of the regional estimation of groundwater runoff (Raikova et al., 1974; General Master Plans, 2000) for Tundja river valley reflects on the non-uniformity of groundwater runoff generation. These groundwater discharge values (expressed in liters per second per square kilometer), characterizing the natural productivity of aquifers or aquifer systems, are the main indicator of groundwater resources availability in an area (Zektser & Everett, 2004).

Within the Tundja river basin, the most productive are porous aquifers in Quaternary alluvial and proluvial sediments (natural groundwater resources amount to 4230 l/s, or 84.7 %), 610 l/s (12.2 %) are due to karst and fissured-karst waters, and 155 l/s (3.1 %) due to Neogene aquifer (General Master Plans, 2000).

Low productive formations cover 2145 km^2 of the river basin, and may be useful only for local water supply. Practically unwatered formations cover 3875 km^2 (49.2 %) of the river basin (General Master Plans, 2000). These formations cannot sustain baseflow in streams crossing through them, for that reason these streams are intermittent or with minimal baseflow.

General characteristics of groundwater bodies

In completing the requirements of the EU Water Framework Directive in Bulgaria, groundwater bodies (GWB) in Bulgaria have been identified and delineated together with their initial characterization. The GWB identified in the Tundja river basin are depicted in Figure 2, and some of their main characteristics are presented in Table 1.

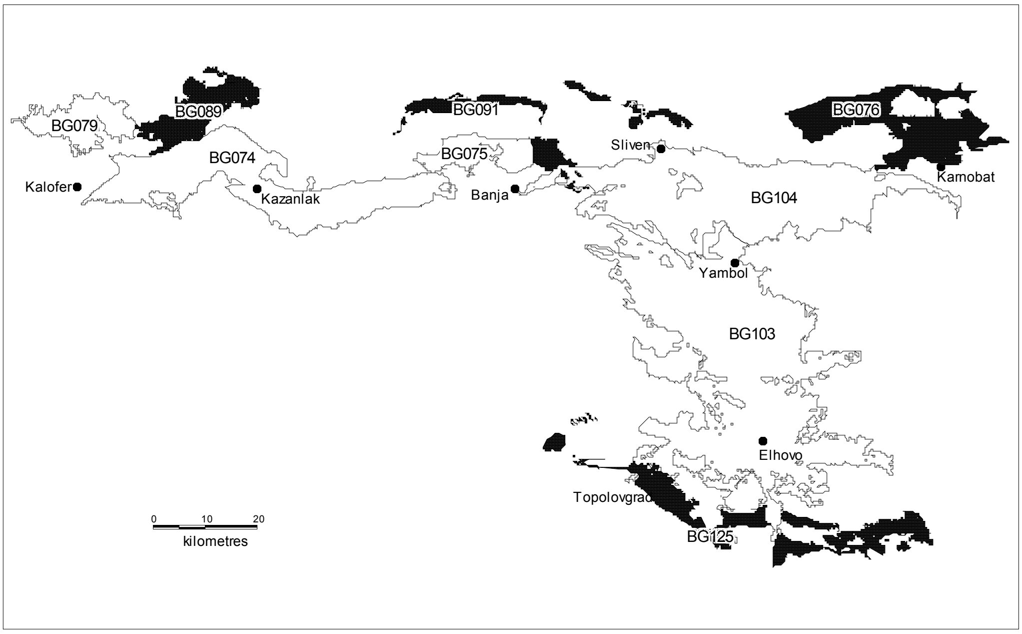

Figure 2. GWB in the Tundja river basin

Most of the above mentioned GWB are situated entirely within the borders of the river basin, and some of them – only partly. The Topolovgrad karst basin (BG125) is a transboundary one, shared between Bulgaria and Turkey.

Evidently, within the Tundja river basin there are no large and deep aquiferous formations with huge groundwater resources. On the contrary, there are many local aquifers. Specific feature of these aquifers is their close connection with river flow.

Groundwater resources are non-evenly distributed within the Tundja river basin. Porous aquifers are formed along the river course. The slopes of the watershed are usually built from low productive fissured rocks. Few but important exceptions are aquiferous karst and fissured-karst groundwater bodies in the upper (BG079, BG089 and BG091) and lower parts of the river basin (BG125).

Table 1 Summary of the GWB in the Tundja river basin

N GWB	*Name of GWB*	*Geol. age*	*F, km²*	*Aquiferous formations*
BG074	N-Q aquifer of Kazanlak kettle	N-Q	547.1	gravel, sand
BG104	U. Trakiya Lowland -N-Q aquifer in Sliven-Straldja area	N-Q	799.7	sand, gravel
BG075	Quaternary aquifer of Tvarditza kettle	Q	113.2	sand, gravel
BG076	N-Q aquifer of Sungulare-Karnobat kettle	N-Q	290.2	sand, gravel
BG103	U. Thrakiya Lowland – N-Q aquifer in Yambol-Elhovo area	N-Q	1421	sand, gravel
BG079	Maragidik fissured-karst. waterbear. massif	K_2	133.9	cavernous limestone
BG089	Shipka karst. waterbear. massif	T	148.1	limestone, dolomite
BG091	Tvarditza – Sliven karst district	T	120.1	limestone, dolomite
BG125	Topolovgrad karst waterbearing basin	T	249.1	marbles, limestone

Groundwater regime in the Tundja river basin

The regime of groundwater is described on the base of data from National Hydrogeological Network (NHGN) in Bulgaria, found in 1958-1961. NHGN provides time-series for groundwater levels in observational wells and discharge for springs (Orehova & Roussev 2004). Water level in observational wells is measured usually once in a month. In this study, only some specific aspects of the groundwater regime are considered.

Groundwater regime in proluvial fans

The groundwater regime in proluvial fans is characterized with specific features. Aquifers there are recharged through losses of water from perennial rivers or intermittent streams. The diffuse infiltration from precipitation is of minor importance.

An example of water table fluctuations for observational well 310 (NHGN) is given below. It is situated in central part of the Slivenski proluvial fan within groundwater body BG104 (Table 2). Important groundwater recharge of the Quaternary aquifer here is due to waters of perennial river Asenovska that partly looses water within proluvial fan (Raikova, 1973). Such recharge produces considerable rise of the groundwater table. In this region observational wells show large amplitude in groundwater level fluctuations (up to 10 –12 m).

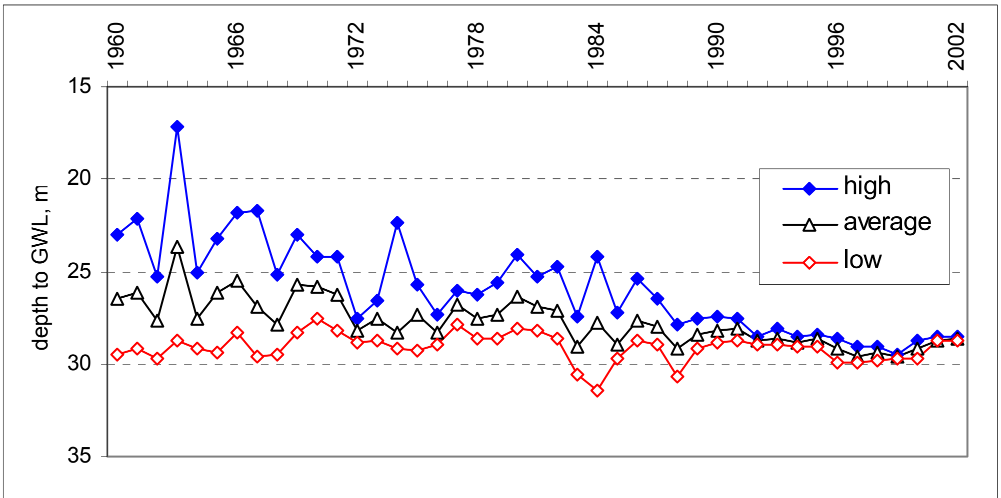

Figure 3. Groundwater level fluctuations for observational well 310 (Sliven)

The peaks of high groundwater levels (GWL) on Figures 3 indicate the recharge events. Such events are manifested with enhanced amplitude for the respective year (Figure 4). Low recharge values lead to decrease of the amplitude - during 1972, 1976 and since 1989.

To quantify this effect, more data on this site are necessary. This important recharge is not regular, and apparently shows its fugitive character.

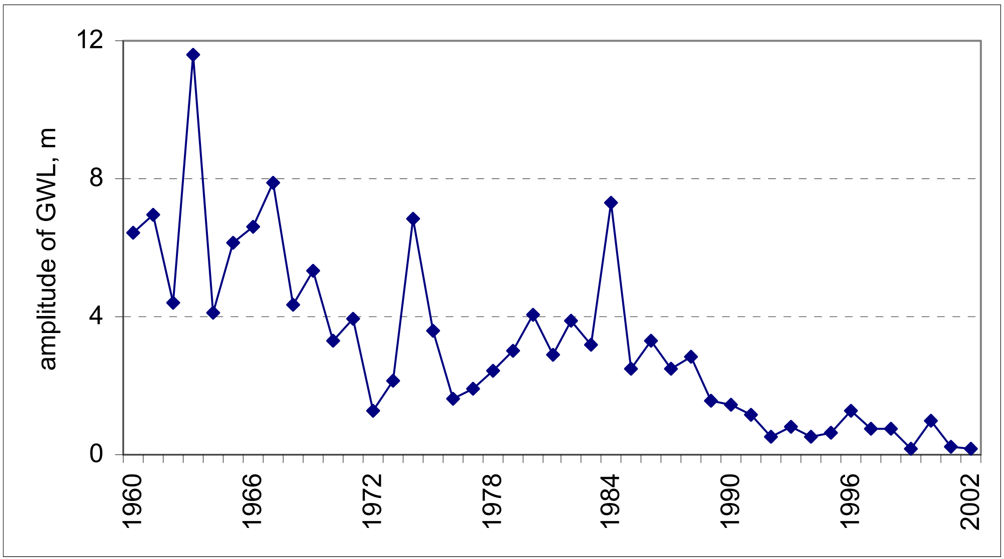

Figure 4. Amplitude of groundwater level fluctuations for observational well 310 (Sliven)

Impact of drought period 1982-1994

Droughts influence over surface water and groundwater along with their interaction. Our previous study (Orehova & Bojilova, 2001) showed negative impact of the 1982-1994 drought period in Bulgaria on shallow porous and karstic aquifers.

To illustrate such impact within the Tundja river basin, several examples of observational wells in porous aquifers are considered. Their multi-annual groundwater levels for the drought and the reference periods are presented in Table 2. The GWL decline during the drought period for the chosen observational wells is in the range between 0.2 to 0.7 m in average for the 1982-1994 period. In the last column of the table, relative deviations are presented. The mentioned observational wells are presented in Figure 1 within the corresponding GWB.

Table 2 Absolute and relative drawdowns of the groundwater levels for the drought period

GWB	***Observation well***	***Geol. index***	***H_{av}, m 1960-2000***	***σ, m***	***H_{av}, m 1982-1994***	***ΔH, m***	***ΔH/σ***
BG074	271 - Tulovo	Q^{al}	2.09	0.351	2.38	-0.29	-0.827
BG074	273 - Dabovo	Q^{pr}	7.02	0.968	7.72	-0.70	-0.723
BG104	310 - Sliven	Q^{al-pr}	27.64	1.278	28.35	-0.71	-0.556
BG103	561– Yambol	N_2+Q^{al}	3.10	0.330	3.33	-0.23	-0.704

H_{av} – multi-annual average water level
σ - standard deviation of H_{av} (1960-2000)

Groundwater level variability for observational wells from the GWB074 is presented in Figure 5, given in relative deviations. The presentation of deviations in relative units allows comparing GWL fluctuations for two wells showing different values of the absolute drawdown.

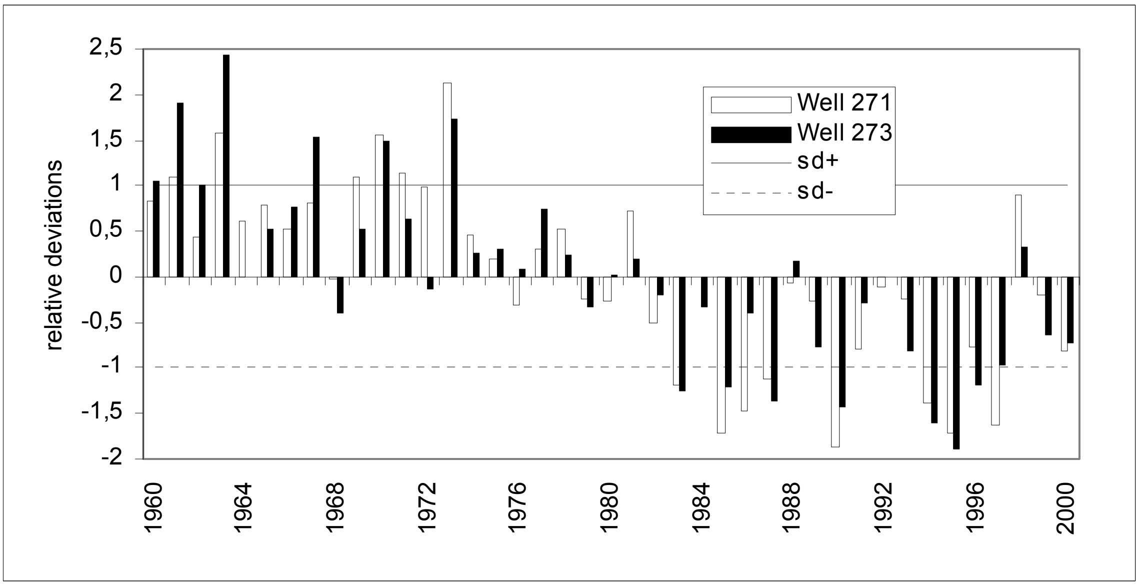

Figure 5. Groundwater level variability for observational wells from the Kazanlak kettle (Orehova & Bojilova, 2004)

Surface water – groundwater interaction

The river and its tributaries

River Tundja accepts 50 tributaries; the most important of them are presented in the Figure 1. The regime of the main river and its tributaries is characterized with periods of high flow in spring months, and low flow in September. More details concerning inter-annual distribution of the river runoff, discharge probability curves, recovered natural and minimum flows, are given by Bojilova (2005a and 2005b).

The value of the runoff modules (M_o, $l/s/km^2$) indicates the intensity of the river runoff from the corresponding area. High runoff modules are manifested in the upper part of the watershed (General Master Plans, 2000; Bojilova, 2005a). The left tributaries from Stara Planina are more abundant in water resources compared with right ones from Sredna Gora mountain chain.

Bojilova (2005c) investigated runoff module in Tundja river basin for recovered natural conditions concerning the 1961-2002 study period. The runoff module was assessed as a function of average mean altitude of the drainage basin. The obtained spatial relationships in graphical and mathematical forms give the possibilities to interpolate and extrapolate in reasonable range.

Some of the tributaries of Tundja are intermittent (not perennial) streams – Turijska, Marash, Sinapovska and many others (General Master Plans, 2000). They loose water on entering the kettles. It is a usual case on the boundary between mountainous areas with steep slopes and adjacent plains. There the subsurface is too permeable to maintain a water table high enough to support gaining streams (Zektser & Everett, 2004). Another possible cause for such intermittent streams - practically unwatered formations that cannot sustain baseflow in streams crossing through them; for that reason these streams are intermittent or with minimal baseflow.

The configuration of the river valley was not constant since its formation. Before tectonic rearrangement, the watershed of Paleo-Tundja covered large areas, including these covered now by some left tributaries of the Maritza River. Paleo-Tundja was nor affluent of the Maritza, nor was part of the Mediterranean basin, but flowed into Black Sea. After one sharp turn to south (that exists now) it flowed to south, and then after another sharp turn to east, continued along the valleys of contemporary rivers Popovska (now tributary of Tundja) and Sredetska (that flows now into Black Sea). This reconstruction of the river network during Late Pliocene (i.e. before its rearrangement) is done by D.Angelova (2003).

Some known cases of surface water – groundwater interaction

River runoff actively interacts with groundwater runoff; and this is an important factor for groundwater formation in the Tundja river basin.

The role of river flow in groundwater regime is twofold – in some reaches and sometimes streams lose water for groundwater recharge, and gain water in another riches. Groundwater discharge is a major component of surface water generation in headwater streams, and is responsible for stream baseflow. Thus, rivers generally drain the aquifers, but in some cases they can lose water feeding the aquifers.

Usually mountainous rivers lose water in entering the plains, thus recharging groundwater. In the downstream sector, the same river may drain the aquifer. The usual locations where groundwater interacts with surface water are on the valley margins, where streams from surrounding mountains enter the plain. Proluvial fans are very permeable in their upper part and offer good possibilities for surface waters to infiltrate. Such example is given for GWB104 in considering the groundwater regime of the Slivenski proluvial fans affected by loosing river.

The close relation between surface and groundwater is evident in cases where the groundwater flow is restrained in narrower sections of the river valley. In the case of GWB103, due to the rock barriers under the water course near villages Konevetz and Kniajevo, the groundwater flow becomes narrower that leads to its discharge in the river course (General Master Plans, 2000).

Generally, in karst terrains the interaction stream – groundwater is more intensive. As a rule, streams loose water in entering on such terrains. In the case of Maragidik karst basin, groundwater feeds the upper affluent of Tundja – river Taja. This karst basin (GWB079) is the rich in groundwater resources owing to combination of two favorable factors: high precipitation amount (due to orographic effect) and karst terrain. Consequently, river Taja shows high values of the runoff module (General Master Plans, 2000).

Discussion

In the Tundja river basin, important recharge of groundwater originates from loosing streams. To quantify this additional recharge, intensive (and expensive) field studies are necessary. The recharge component is often poorly quantified without stream loss gaugings and surface-groundwater interaction monitoring.

Numerous factors are involved in the process of the runoff generating in the river basin. They act in different time and spatial scales. A general view on the wider environment is very useful (if not essential) to solve any practical task. Such look gives special outer “frame” to study a particular problem. In this relation, any general large-scale summary or generalization (either for larger territories or longer periods) is a basic condition to perceive any prominent process, for which it is actually the background.

In such context, the work accomplished by Bojilova (2005a) presents a successful trial for synthesis of hydrological knowledge for the Tudja river basin, and thus giving general view useful for solving of different tasks. The runoff is dynamic process that is controlled by many factors, and involving of additional information would contribute to improving of the results.

Within the Tundja river basin there are no large and deep aquiferous formations with huge groundwater resources. On the contrary, there are many local aquifers. Specific feature of these aquifers is their close connection with river flow. The surface water - groundwater interaction occurs where and when there are hydraulic preconditions for this process, and is not uniform in space and time.

Groundwater discharge is a major component of surface water generation in headwater streams, and is responsible for stream baseflow. On the other hand, important recharge of porous aquifers originates from loosing streams. Usually streams from surrounding mountains lose water in entering the plains, thus recharging groundwater. In the downstream sector, the same stream may drain the aquifer. Just non-uniformity and high variability of this exchange makes the study of this process complicate.

Conclusions

Groundwater is widely used in the Tundja river valley. Recapitulation of groundwater resources in Bulgaria showed that within this watershed water supply takes about 81% of the total exploitable resources (assessed as 4995 l/s), and thus this river basin is subject to high human impact (Spasov et al., 2003).

In the Tundja river basin different kinds of water engineering and works have been accomplished: dams and reservoirs, water supply and irrigational systems, riverbed corrections, excavations for sand and gravel abstraction from the riverbed, draining of swamps, electric power stations, etc. As a consequence, river runoff have been transformed and diminished, and river waters became polluted. Impact on groundwater are or direct (water supply), or through modification in the natural recharge-discharge regime.

Nevertheless, the Tundja river is a beautiful and used for recreation river. Local residents and visitors appreciate the river for its recreational value – rocky landscape around upper tributaries and protected areas in the southern part of the basin. Recreational use of the Tundja River, and the dams – fishing, as well as water tourism and aquatic sports (swimming, boating, rafting, boat rowing, etc.) is favoured by picturesque places along the Bulgarian rivers and dams.

Tundja river valley proposes many picturesque views for tourists and inhabitants. The area of Kazanlak is known as the Valley of the Roses owing to the vast fields of oleaginous roses. Thanks to the favorable climate the rose-oil produced here is of superb quality. Tourists are attracted as well as by gold, silver and bronze artifacts found in the region. Archaeological relics testify to ancient settlements in the river basin. The most impressive monuments from the rich Thracian heritage are listed under the protection of UNESCO's World Heritage Scheme. Protected areas and reserves are rich in flora and fauna.

Important task of the present generation is to preserve the beautiful nature in this river basin. It is known that good management is not possible without good knowledge of the object. One of the basic characteristics of the Tundja river basin is close relation between surface and groundwater. The main complexity in assessing of the stream leakage from major rivers and other smaller streams traversing the aquifer is related to the variability of this process in space and in time.

It seems that many efforts are necessary in future to bridge together different pieces of knowledge. The cooperation between experts in different branches of the science (meteorology, hydrology, geology, hydrogeology, ecology, etc.) would give fruitful results in research of the water resources and evolution within a river basin.

Acknowledgements

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