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Main Characteristics of Water Regime of the Phreatic Aquifer in Subotica Municipality (Vojvodina, Serbia)

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Abstract

Subotica municipality is situated in the Subotica-Horgoš sands in the Bačka loess plateau, the two geomorphological units made of the early Quaternary sediments of intergranular porosity which form the water collecting environment for the phreatic aquifer. Owing to this, the phreatic aquifer is developed within the whole study area.

Because of incomplete database, primarily the lack of contemporary data of the phreatic water table depth from various measuring points, the main aims of the paper are restricted to defining basic characteristics of water regime of the phreatic aquifer in Subotica municipality and their causal connection with the dominant climatic factor. Special emphasis in the paper is given to the issue of inadequate monitoring of water table depth in the study area, which is the result of insufficient coverage of the area with active monitoring wells. Actually, there are only 10 active monitoring wells in Subotica municipality, which are unevenly distributed in the study area. Such situation disables the studious approach in studying the water regime of the phreatic aquifer and estimating the exact directions of its outputs, which creates a significant problem that needs to be solved in the near future.

Key words: phreatic aquifer, water regime, Subotica municipality, Vojvodina, Serbia

Introduction

Formation and distribution of the phreatic (unconfined, free, first, shallow) aquifer, groundwater layer the closest to topographic surface, primarily depends on the ruling hydrogeological conditions and relations that are perceived in the presence of rocks of intergranular porosity with favourable water collecting abilities within the top (covering) geological layer and impermeable rocks in the bottom geological layer of a certain geological complex. Main characteristics of the phreatic aquifer water regime result from the series of complex and interdependent phenomena and processes whose character is defined by numerous natural and anthropogenic factors. Among the natural factors, besides above-mentioned hydrogeological conditions, it is necessary to mention pedological, geomorphologic, fitogeographical and especially climate and hydrological circumstances. However, anthropogenic factor significantly modifies the natural regime of the phreatic aquifer in the areas with appropriate hydrotechnical works conducted or intensive irrigation/drainage of cultivated land (Pavić, 2006; Pavić et al., 2006; Pennington, Cech, 2010).

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In agricultural areas similar to Vojvodina, the phreatic aquifer represents highly significant natural resource for agriculture. On the other hand, phreatic waters may cause damages e.g. floods of arable land and lower parts of settlements which occur during wetter periods, when the phreatic water table frequently reaches the topographic surface. Numerous authors have been dealing, primarily due to the above-mentioned reasons, with the problem of water regime of the phreatic aquifer and impact of natural and anthropogenic factors on forming its main characteristics in different parts of Vojvodina (Milošev et al., 1977; Vasileva, 1978; Dedić et al., 1984; Stojšić, 1994; Marković, Bogdanović, 1995; Marković, 1996; Pavić, 2006; Pavić et al., 2006 and other).

The main aims of the research in this paper are to establish major characteristics of the water regime of the phreatic aquifer in Subotica municipality, to highlight the problem of inadequate monitoring of water table depth in the area and to emphasise the need for establishing a denser network of monitoring wells. Also, one of the aims in this paper is to support the findings on water regime of the phreatic aquifer in Vojvodina.

Study Area

Subotica municipality is situated in the north part of Autonomous Province of Vojvodina, the Republic of Serbia. It occupies northern part of Bačka, one among three territorial units of Vojvodina (Figure 1). The territory of Subotica municipality borders the Republic of Hungary to the north, the municipality of Kanjiža to the east, the municipality of Senta to the south, the municipality of Bačka Topola to the southwest and the municipality of Sombor to the west. Subotica municipality covers 1,007 km² which is 10.9% of Bačka, or 4.7% of the territory of Vojvodina. Beside the urban center of Subotica and Palić which has urban and rural character, seventeen other rural settlements are located in the research area (Kovačević, 2006).

The territory of Subotica municipality stretches on two relief units, the Subotica-Horgoš sands and the Bačka loess plateau where the sands covers about 20% and the plateau about 80% of the territory. The sands stretches in two narrow fragments in the far north and north-east and the plateau covers the rest of the study area. Geological formation of these relief forms consists of Quaternary sediments, primarily the eolian sand and loess which were deposited by wind during the Pleistocene (Marković-Marjanović, 1977; Bukurov, 1975).

The Subotica-Horgoš sands is gently slanted towards the south, south-east and south-west. Its highest parts are situated south and south-west of Subotica, next to the state border with Hungary, where its elevation rise to 143 m. The sands has the typical eolian relief forms: dunes and inter-dune depressions. There are narrow river valleys in the sands, formed by water courses (Krivaja, Kereš) which flow towards the plateau as a lower relief unit. The Bačka loess plateau is wide and most striking relief entity in Bačka. It covers the area of about 2,800 km² out of which 30% is within the borders of Subotica municipality. The Bačka loess plateau represents a wide, mildly domed elevation declining from the north and north-west to the east, south-east, south, south-west and west. Its elevation within the study area ranges from about 130 m in the north-west and 100 m in the furthest south-east. There are specific micro relief forms at the plateau: dunes, intercoline depressions, loess valleys, flood plains, etc. (Bukurov, 1975; Bukurov, 1983; Kovačević, 2006; Pavić, 2006; Pavić et al., 2006).

Subotica municipality is situated in the area of moderate continental climate (Katić et al., 1979). According to average annual air temperatures for the perennial period (1951–2010) at meteorological station of Palić (*46°06' Nφ and 19°46' Eλ, 102 m*), January is the coldest month and the only one with negative mean monthly air temperature (-0.9°C), whereas July is the warmest month (21.0°C). The mean monthly air temperature increases continually from January to July, and then decreases continually to the end of the year. The mean annual air temperature for perennial periods is 10.9°C. Mean air temperature in winter is 0.4°C, in spring 11.1°C, in autumn 11.0°C and in summer 20.9°C. Vegetation period has mean air temperature of 17.8°C.

Perennial data on precipitation (1951–2010) from the meteorological station of Palić indicate prominently uneven annual distribution. However, during February and March mean precipitation is 32 mm and in June 75 mm. Mean precipitation continually increases from February–March minimum towards its maximum in June and then continually decreases to October. In November precipitation records a slight increase and then continually decreases towards February–March minimum. Mean annual precipitation for the meteorological station of Palić is 558 mm. The maximum precipitation occurs in summer (186 mm), followed by spring (131 mm) and autumn (127 mm), and the minimum in winter (114 mm). Mean precipitation for the vegetative period is 328 mm.

Surface waters of Subotica municipality are represented by smaller natural water courses, canals and both natural and artificial lakes. The upper courses of rivers Krivaja (121 km), Čik (102 km) and Kereš (70 km) flow through the area covered in the study. Among the canals, the most important by their sizes are the Palić–Tisa Canal, the Bega Canal, the Radanovački Canal and the Bajmočki Canal. The natural lakes are the Palić lake (5.76 km²) and the Ludaš lake (3.14 km²), as well as the Kelebijsko lake and the Krvavo lake, which have almost

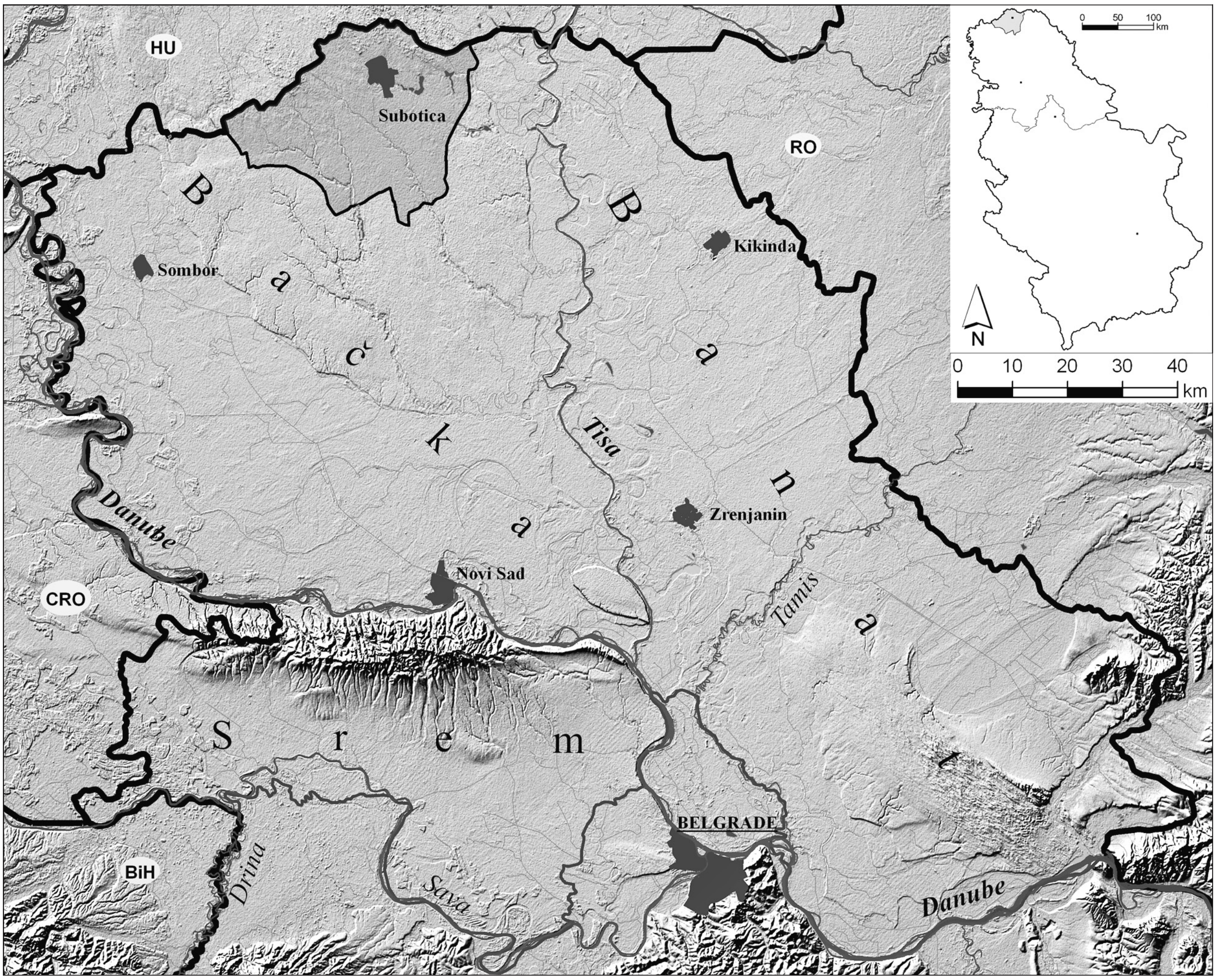

Figure 1. Geographical position of Subotica municipality in Vojvodina and Serbia

disappeared. The artificial lakes are represented by small accumulations of water (2–45 ha) on the Krivaja river (Tavankut, Đurđin, Pavlovac, Krivaja) and on the Čik river (Čantavir) and lakes created by exploatation of materials (the Majdan and Treset lake) (Kovačević, 2006).

Within the study area, there is a heterogeneous soil cover represented by various soil types: initial soil on sand, brown steppe soil on sand, cernozem, humogley and semigley, bog peat, solonetz and anthropogenic sand (Živković et al., 1972a,b; Kovačević, 2006). The largest portion of the study area is covered in agricultural vegetation. In the northern parts, on the sands, there are vineyards and orchards, among agricultural vegetation, primarily corn, wheat and sunflower are found. In the area of Subotica municipality, there are woods, primarily wood complexes in the Subotica-Horgoš sands and fragments of moors and grass vegetation (Kovačević, 2006).

Materials and methods

The data about the observations of the phreatic water table depth, taken from the database of Public water management company "Vode Vojvodine", have been used as basis material for the analysis of water regime of the phreatic aquifer in the study area. A systematic observation of water table depth (2–3 times monthly) on the territory of Vojvodina started in the second half of the 20th century. Only on the territory of Bačka, over 430 (dug) monitoring wells (or piezometers) were established. However, in the following few years, the observations were not carried regularly in a number of wells, whereas some other wells stopped functioning completely. In the meantime, at certain localities new drilled wells were established in different periods (Pavić et al., 2006).

Such circumstances are distinctive characteristics of Subotica municipality, where about forty monitoring wells were used for observations of the phreatic aquifer water table depth at different periods. Today only ten unevenly distributed wells are in function in the study area which caused a huge problem for the analysis of water regime of the phreatic aquifer. In fact, in order to cover the largest possible part of the study area, the data on depths of the phreatic aquifer water table from eleven wells were used in the paper

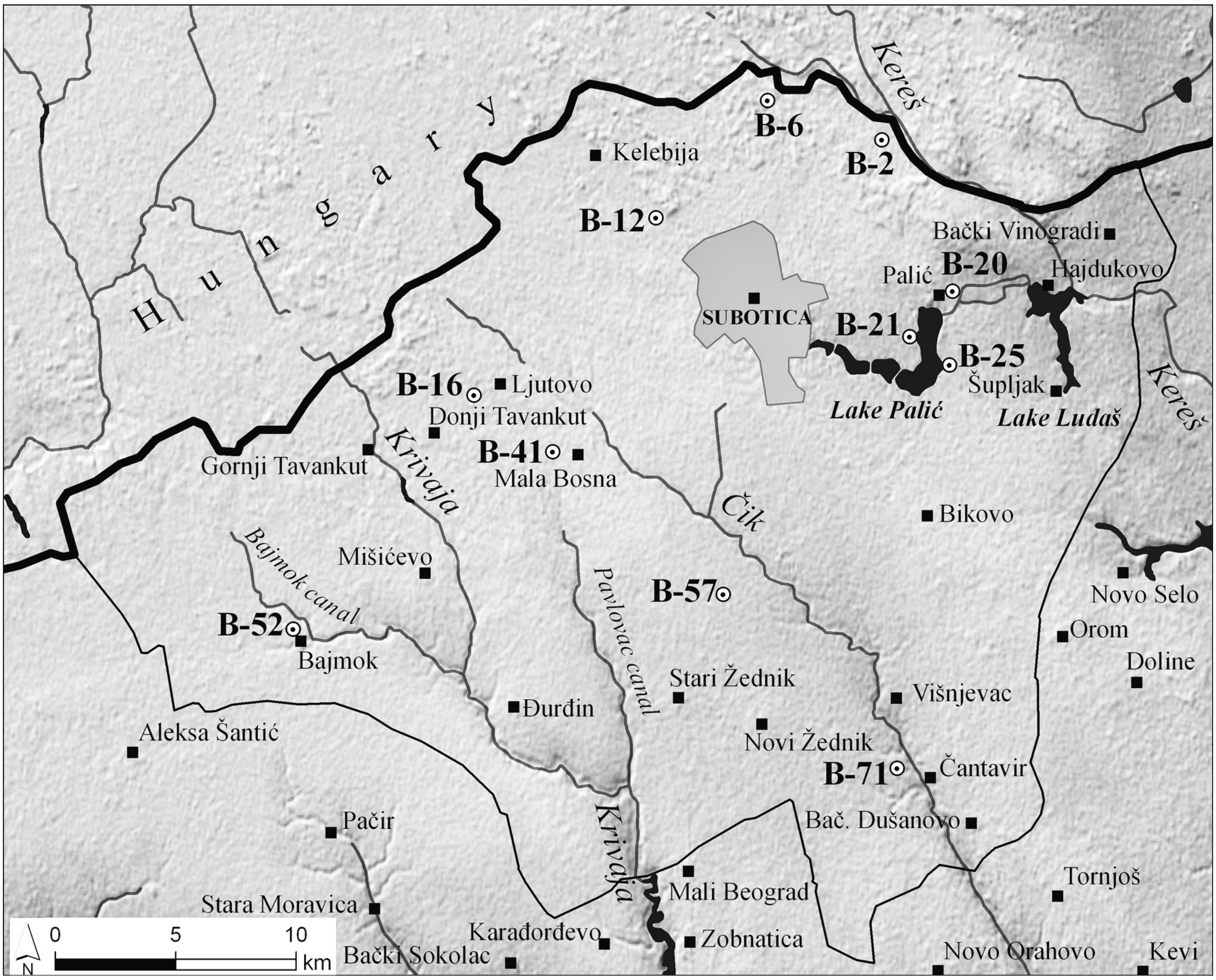

Figure 2. Position of the analysed wells

(Figure 2). The wells are relatively evenly distributed over the territory and the data obtained cover five different perennial periods (1951–1980; 1952–1977; 1973–2010; 1991–2010; 1995–2008). Out of the 11 chosen wells, only 4 wells (B-2, B-6; B-52, B-71) are active at present.

The other material includes the perennial data about mean monthly and annual air temperatures and precipitation of the meteorological station of *Palić*, as well as the rich cartographic material and reference resources.

The main characteristics of water regime of the phreatic aquifer in the study area are defined by means of the analysis of annual variation of mean monthly phreatic aquifer water table depths for eleven monitoring wells in perennial period. The estimation of the influence of dominant climatic factors on the phreatic water regime of the study area has been done through the comparison of annual variation of the mean monthly values of the water balance of climatic factors with the annual variation of the mean monthly phreatic water table levels for two representative wells (for perennial period), one at the Subotica-Horgoš sands and one at the Bačka loess plateau. The water balance of the climatic factors represents the difference between the total precipitation and evapotranspiration which stand for vertical climatic factors of water balance (Marković, 1996). The mean monthly values of potential evapotranspiration were calculated by the *Türc* formula for the meteorological station Palić. The *Türc* formula is as follows:

$$\mathbf{ETP = 0.40\ t \div (t + 15)\ (J_g + 50)}$$

ETP – *evapotranspiration for the given month*
t – *average monthly air temperature (°C)*
J_g – *intensity of sun radiation*[1] *(gr cal/cm²)*

Results and discussion

Owing to favourable hydrogeological characteristics and conditions that are provided by continuously present Quaternary sediments of intergranular porosity, the phreatic aquifers found in the whole area of Subotica municipality. Namely, the role of water collector is

[1] Data given by Katić et al., 1979.

here primarily assigned to the early Quaternary sediments represented by loess, sandy loess and the eolian sands (Josipović, 1985). In their bottom layer, at the depths ranging from several metres to several dozen metres, there are impermeable clay layers that simultaneously represent the lower boundary of the phreatic aquifer. Favourable filtration abilities are found, besides the above-mentioned sediments, with majority of the soil cover in the study area (initial soil on sand, brown steppe soil on sand, cernozem), which is essential with regard to the input of atmospheric water to the phreatic aquifer, and simultaneously its influence on the water regime (Pavić, 2006; Pavić et al., 2006).

Characteristics of water regime of the phreatic aquifer may be observed through the analysis of the water table level oscillations and estimation of the size and forms of various factors that cause oscillations. According to dominant natural and anthropogenic factors, M. Stojšić (1994) classifies 4 types of water regime of the phreatic aquifer in Vojvodina:

- *climatic type* – as the most frequent, it is formed under the influence of climatic factor, primarily precipitation and temperature conditions;
- *hydrological type* – formed under the influence of large water courses (the Danube, the Tisa and the Sava);
- *climatic-hydrological type* – formed under joint influence of climatic and hydrologic factors in their influence transfer zone;
- *climatic-anthropogenic and hydrological-anthropogenic type* – formed by artificial modification of natural regime (melioration, hydrotechnical measures, etc.).

The data on mean monthly phreatic water table depths presented in table 1 indicate the dominance of climatic factor and prevailing climatic type of water regime of the phreatic aquifer in the study area. First of all, due to the lack of necessary perennial values about the depths of the phreatic aquifer from various characteristic localities, the representativeness of other regime types fails to be discussed with arguments. Regarding the presence of surface hydrologic objects and hydro-technical and melioration measures undertaken, it may be assumed that in certain smaller zones other, separated types of regimes occur.

As it has been already explained, within this study, the data about the depths of the phreatic water table have been used from the observations on the 11 monitoring wells. Four wells are situated in the Subotica-Horgoš sands (B-2, B-6, B-12, B-20), five in the Bačka loess plateau (B-16, B-41, B-52, B-57, B-71) and two in transitional sand-loess zone (B-21, B-25), more precisely in the west and east coastline of the Palić lake (Figure 2). The above-mentioned problems are related to the lack of higher number of active monitoring wells and the fact that the data on water table depth refer to five different perennial periods which disable more serious analysis of the phreatic aquifer regime of the study area. However, owing to the fact that for each of the observed wells there are necessary data for the perennial periods varying between 14 and 38 years, and the fact that the wells are almost evenly distributed at the study area, the wells may offer general overview of annual variations of water table depths and the range of its annual oscillations in different parts of the study area. The analysis of data in table 1 provides the following observations:

- *minimum mean monthly depths of phreatic water table* within the study area occur the most frequently in spring (April and May). April minimum (B-6, B-20, B-21, B-25) and May minimum (B-16, B-57, B71) are registered at four (April) and three (May) wells whereas identical minimum depth values during two month periods (April-May and May-June) are registered at two monitoring wells (B-2 i B-52). Besides this case, slightly moved in time with regard to the expected May-June minimum, which was registered in the far west part of the study area (B-52, Bajmok), another case of unexpected July mean monthly minimum of water table depth was registered southeast from Subotica (B-41, Mala Bosna). The available data indicate that in the north and north-east parts of the study area, i.e. the Subotica-Horgoš sands and transitional sandy-loess zone near the Palić lake, the minimum of the water table depth occurs mainly during April and in the other parts of the study area, precisely at the Bačka loess plateau, most frequently a month later in May.
- *maximum mean monthly depths of the phreatic water table* in the study occur most frequently in autumn, especially during October and November. October maximum is registered at five (B-2, B-20, B-21, B-25, B16) and November maximum at three wells (B-52, B-57, B-71). Identical values for maximum water table depth are registered at two wells (B-12 i B-6) during two months (September-October and October-November). Moreover, at one well on the loess plateau, southeast from Subotica (B-41, Mala Bosna) an unexpected December maximum of water table depth was recorded. The available data generally indicate that in the northern part of the study area (the Subotica-Horgoš sands and northern parts of the Bačka loess plateau) the highest mean monthly water table depths occur most frequently in October, i.e. a month or two earlier than in other parts of the study area;
- *the smallest phreatic water table depths* are found in northern parts of the study area, in the Subotica-

Table 1. *Mean monthly and mean annual phreatic water table depth (cm) in perennial period for the area of Subotica municipality*

Wells	Elev. (m)	Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean annual
B-2	112.58	'73-'10	149	142	143	131	131	134	140	147	156	159	158	155	145
B-6	117.15	'73-'10	205	194	185	179	180	182	188	197	208	214	214	210	196
B-12	126.18	'51-'80	176	167	162	161	159	168	181	195	207	207	202	193	181
B-20	103.42	'51-'80	157	146	128	120	122	132	150	169	183	184	180	172	154
B-21	105.13	'52-'77	316	299	285	281	293	295	308	319	338	339	336	328	311
B-25	102.64	'52-'77	235	223	209	206	209	223	235	249	263	264	258	245	235
B-16	128.31	'51-'80	567	563	545	535	528	536	547	560	573	586	576	580	558
B-41	121.74	'51-'80	862	859	861	856	852	850	848	853	856	860	863	864	857
B-52	116.19	'91-'10	721	712	706	703	695	695	697	709	722	730	731	726	712
B-57	109.62	'51-'80	545	525	499	480	465	469	481	503	526	548	557	555	513
B-71	104.56	'95-'08	723	716	717	717	714	718	727	733	740	743	744	737	727

Source: Public water management company "Vode Vojvodine"

Horgoš sands (due to a shallow impermeable geological layer and inflow of the groundwater from elevated parts of the sands in Hungary and water accumulation in sandy sediments) (Pavić, 2006), which is documented by mean annual depths ranging from 145 to 196 cm at four wells. Unlike the Subotica-Horgoš sands, at the Bačka loess plateau the water table depths are significantly higher. That is to say, mean annual water-table depths at five available wells range from 513–857 cm;

- *annual amplitudes of mean monthly water table depths* at the sands range from 28 cm (B-2) to 64 cm (B-20), at the loess plateau from 16 cm (B-41) to 92 cm (B-57), whereas in the transitional zone, near the Palić lake, the amplitude for both analysed wells (B-21, B-25) is 58 cm. Annual amplitudes for absolute extreme monthly depths in perennial period are significantly higher.

The dominant influence of the climatic factor on phreatic aquifer water regime in the research area has been confirmed by comparative analysis of annual variations of mean monthly values of water balance of climatic factors[2] for the meteorological station Palić and annual variation of mean monthly phreatic water table level for two representative wells (B-12 in Subotica-Horgoš sands and B-57 in Bačka loess plateau). The data refer to perennial period. In both cases, dependence of mean monthly water table level change from annual variations of water balance of climatic factors is clearly visible (Figure 3 and Figure 4). More precisely, the highest monthly water table levels in spring reaching their maximum in May (B-12, B-57) are the result of the prevailing positive climatic water balance between November and March. The lowest mean monthly water table levels in autumn reaching their minimums in September and October (B-12), i.e. in November (B-57) are the result of negative climatic water balance between April and October.

Out of the total of 11 wells surveyed, it is only the well B-41 where the annual variation of mean monthly phreatic water table level deviates from the general trend of spring maximums and autumn water table level minimums. Namely, as it has been previously indicated, July maximum and December minimum of the water table level were recorded at this well. Moreover, this well is characterized by a very even water table level, i.e. the depths of phreatic water table during the year, which is implied by the mean annual amplitude of only 16 cm for perennial period. The causes of such phenomena cannot be elaborated in detail since additional experimental research has not been conducted. Unfortunately, the well B-41 has been out of order for a long time and there is no new active well at the same location for conducting such research. However, it can be assumed that the delay of monthly maximums and minimums are to a certain point connected to hydrological influence (aquifer feeding) of the two water flows, the river Čik and the Pavlovački canal, between which the well B-41 was situated. On the other hand, extremely small annual amplitude of water table level is the consequence of the significant depth of the water table which diminishes the impact of evapotranspiration on the phreatic aquifer water expenditure.

[2] Since the potential evapotranspiration obtained by calculation is frequently above the real value, water balance of climate factors in this particular case has negative values for seven months (April–October). However, the obtained values indicate the approximate annual amplitude of this parameter which confirms the dominant influence of climate factor in defining the main characteristics of water regime of the phreatic aquifer in the study area.

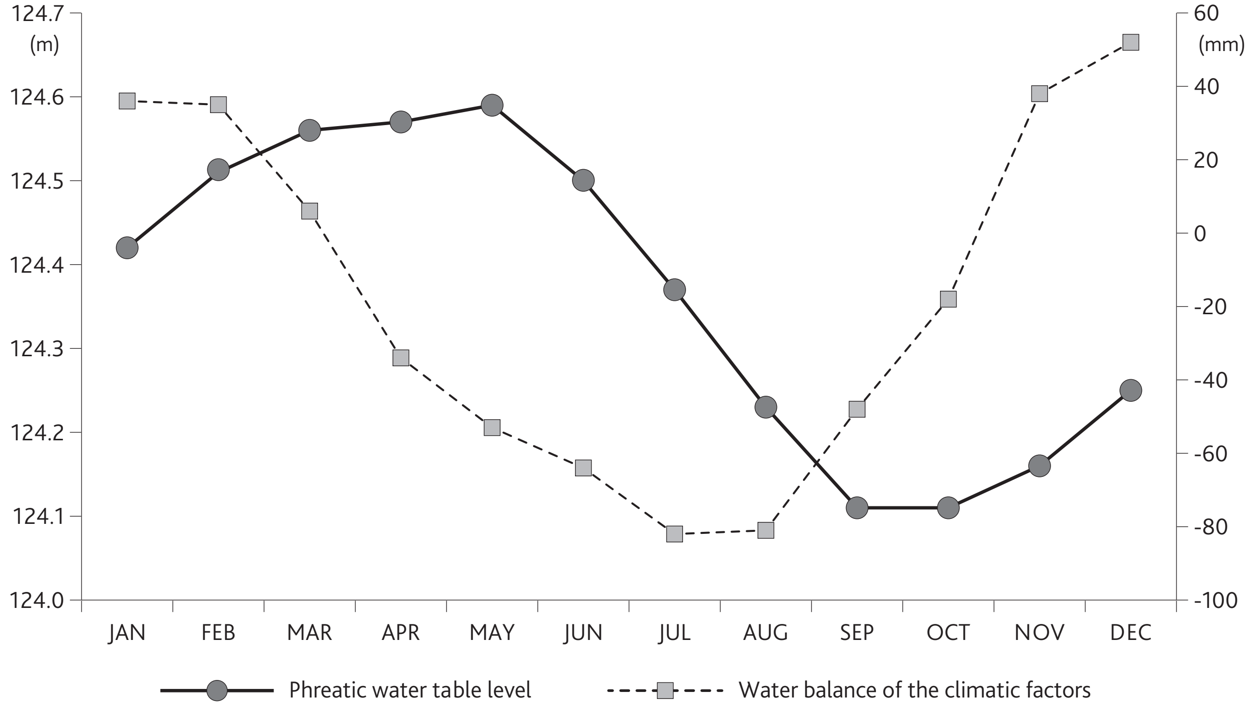

Figure 3. Ratio between mean monthly values of water balance of the climatic factors for m.s. Palić and mean monthly phreatic water table level at well B-12 (perennial)

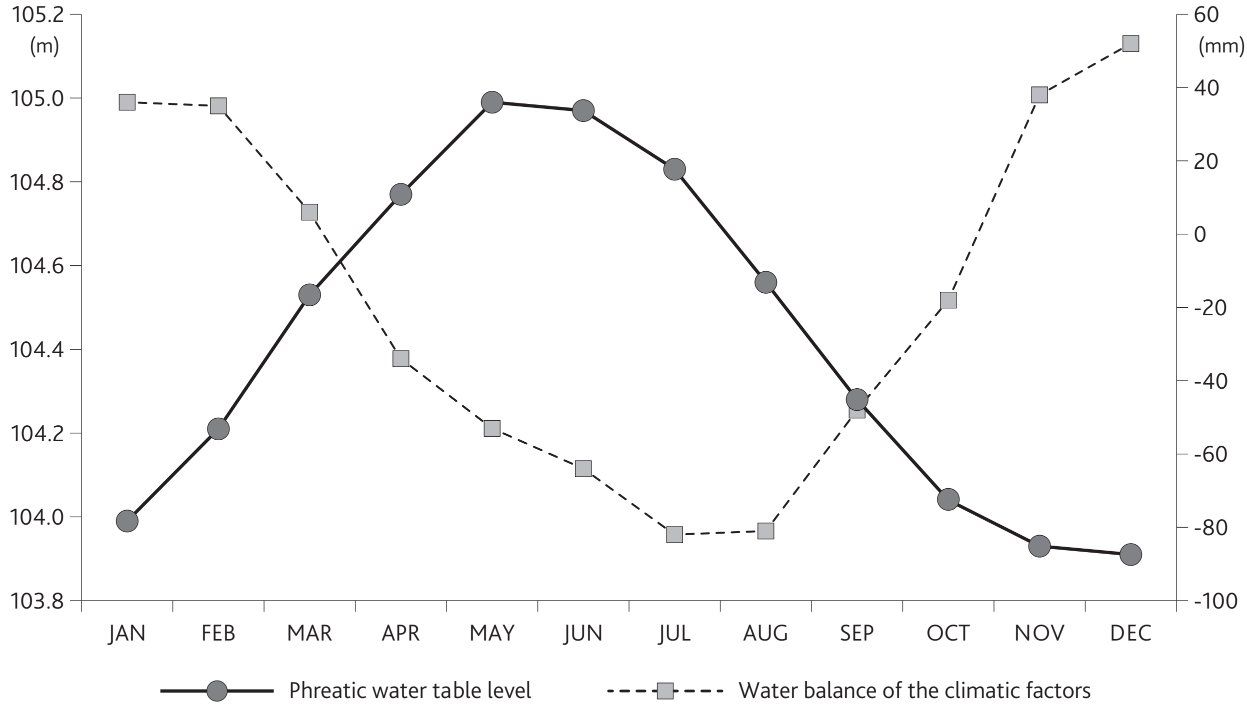

Figure 4. Ratio between mean monthly values of water balance of the climatic factors for m.s. Palić and mean monthly phreatic water table level at well B-57 (perennial)

In addition to oscillations of water table, as a vertical component of the phreatic aquifer movement, primarily caused by a climatic factor, in the study area there is prominent horizontal movement of the phreatic aquifer caused by the relief, i.e. terrain topography and inclination. This is indicated by older references such as Regional spatial plan of SAP Vojvodina (1974), made at the time when there were numerous active monitoring wells distributed within the network, which enabled serious studies of problems related to the phreatic aquifer flow directions. According to the map from this reference, the drainage directions of the phreatic aquifer in the area of Subotica municipality are in concordance with the general slope of the terain. Namely, the phreatic aquifer is generally moving in the northwest to southeast direction, i.e. towards the river Tisa as the major recipient of waters in this area. In the current situation with only ten active monitoring wells, which are unevenly distributed at the study area, serious research on the issues regarding relief impact on flow directions of the phreatic aquifer is not possible, which is the most significant problem in determining the main characteristics of its water regime.

Conclusion

It is necessary to highlight within the final remarks that the results of the research for this paper, obtained on scarce data on depths of phreatic water table depths, provide only a general overview of the main characteristics of the phreatic aquifer water regime in Subotica municipality. In fact, the results indicate the dominance of climatic factor and prevailing presence of climatic type of the phreatic aquifer water regime in the study area. It is indisputable that climatic factor is the most dominant, as in other parts of Vojvodina, but not the single one that influences the water regime of the phreatic aquifer. It would be enough to take into account the facts that the area of Subotica municipality has natural and artificial lakes, rivers, canals, dynamic eolian relief forms, versatile soil and vegetation cover and that the area is primarily agricultural with application of melioration and irrigation/drainage measures to rightfully conclude that there are also other factors that modify at least secondary or fragmentary and influence the formation of the water regime of the phreatic aquifer characteristics.

In order to estimate the influence of the abovementioned factors and presence of other types of water regime of the phreatic aquifer (hydrological, climatic-hydrological, climatic-anthropogenic and hydrological-anthropogenic) in the area of Subotica municipality, first it would be necessary to establish a much more serious system of monitoring the depths of the phreatic aquifer. Namely, with the establishement of a larger number of monitoring wells, which would cover the researched area with a more frequent water table level monitoring (according to the current methodology in Subotica municipality, the depths are monitored monthly twice), a much more realistic insight in the phreatic aquifer water regime and the strenght of influence of individual factors on its forming in various parts of the research area would be obtainable. Moreover, it would contribute to not only more precise estimation of the phreatic water flow directions, but also for estimating the amount of the water input from elevated parts of the sands in Hungary.

There are several reasons to justify a more studious approach in monitoring and studying the phreatic aquifer in Subotica municipality. Above all, because the Subotica-Horgoš sands and the Bačka loess plateau in the research area, thanks to the favourable water collecting ability of its geological sediments, are water rich collector areas of phreatic groundwater. In addition, the phreatic aquifer is a significant natural resource for a primarily agricultural area, and also because of the need for timely prevention measures for disasters and damages caused by flooding of arable land and settlements due to increase in phreatic water table during extremely wet periods.

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