MUTUAL RELATION OF RIVER WATER AND GROUNDWATER IN THE AREA OF HYGROPHILIC FORESTS IN THE RAVNI SREM DOWNSTREAM OF SREMSKA MITROVICA, SERBIA

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Abstract: During the last century, the significant hydrological changes that have taken place in the Ravni Srem, as a result of antrophogenic activities, had an impact on the availability of water to the hygrophilic forests in this area. After the construction of the embankment for the defense of the flood waters from the Sava River and because of it, the absence of seasonal flooding, the hygrophilic forests have begun to dry individually and the process of their fragmentation has begun. The aim of the conducted researches was to assess the fluctuations of the groundwater levels in the case of Podlužje in the Ravni Srem, and for the purposes of the functional stability of the hygrophilic forests. The Sava River water level, fluctuation of groundwater levels and amounts of precipitation were analysed for the period 1992-2013 for the area of Podlužje. Input data were taken from the database of the Republic Hydrometeorological Service of Serbia. Groundwater level was analyzed for five individual piezometers and two batteries of piezometers, the Sava River water level was analyzed for three hydrological stations, and precipitation was analyzed for five rainfall stations. Calculated values are shown in the comparative diagrams by months and annual seasons, excluding the vegetational season. Conducted analyses show a significant dependence of the groundwater level fluctuations from the Sava River water level, as a result of direct hydraulic connection of surface water and groundwater. The obtained results can be in the function of forecast of groundwater levels in Podlužje and by that, contribute to more successful hygrophilic forests management in terms of planned redistribution of the area utilization.

Key words: hygrophilic forest, alluvial plain, groundwater; Sava, Ravni Srem.

INTRODUCTION

By the whole length of the southern border of the Srem, a spacious alluvial plain extends, which is parallel to the river flow of the Sava River. Mainly wetlands are represented in this area, where aquatic and coastal ecosystems with a very rich biodiversity have been formed. In previous centuries, in the area of the alluvial plain of the Sava River in the Srem, the hygrophilic forests were developing solely under the influence
of natural factors. Rainforests were growing on fertile soil and favourable water regime in the enormous area. Biogeocenotic balance ruled there which was the reflection of a good consistency of the relations between soil, climate, water, flora and fauna. Raising the embankment on the left bank of the Sava River, starting from 1904, following by its upgrading (increasing elevation embankment) in the period from 1946 to 1956 (Vujović and Raštegorac 2002), leads to significant changes in the natural hydrological regime.

The large alluvial plain of the Sava River in Srem was singled out as a natural-economic entity and represents the working area and biological-material basis in forest production (Glavač 1962). On the territory of Serbia, the forests of the Ravni Srem are the best quality hygrophilic forests of highly productive forest stands and fall into technically the most valuable forests in the Balkans (Tomić 2004). Because of its hygrophilic characteristics, which are under the direct influence of different forms of some of the water resources (surface water and groundwater and precipitation), the hygrophilic forests are among the most endangered forests in Europe (Čater et al. 2008), and thus in Serbia as well. Drying of these forests is one of the major limiting factors of planning and forest management today (Letić et al. 2014). Intensification of this process leads to losses in production, breaking of the composition and stability of forest stands, inability to realize the goals and respect the prescribed measures of forest management, jeopardizing real management plans, and thus calls into question the viability of forest ecosystems potentials management in the Ravni Srem (Medarević et al. 2009).

In this paper, the analysis of mutual relations of surface water and groundwater was conducted for one part of the Ravni Srem, represented by the area of Podlužje. The aim of the research is the analysis of fluctuations of groundwater levels in Podlužje, but in terms of the functional stability of the hygrophilic forests.

MATERIAL AND METHOD

Of many influencing factors of the habitat in Podlužje, where the hygrophilic forests grow, the water regime or wetting (floodwaters, atmospheric precipitation and fluctuations in groundwater levels) is one of the most important. The area of Podlužje extends along the left bank of the Sava River, in the direction from Sremska Mitrovica (139 km from the confluence of the Sava and Danube) to Boljevci (34 km). The absolute height of the terrain near Sremska Mitrovica is in the altitude of about 79 m, and in Boljevci of about 75 m. For the area of Podlužje, the regime of fluctuation of the groundwater levels was analyzed based on data from five individual piezometers (Obrež, Hrtkovci, Prhovo, Sremska Mitrovica No. 67 and 85) and from two batteries of piezometers which have a total of nine piezometers (Nikinci and Lačar), the regime of surface waters was analyzed from three hydrological stations on the Sava River, of which the measurement of the water level is done by the use of gauging rail at two stations (Šabac and Beljin), and in one the measurement of discharge and water level was done by limnigraph (Sremska Mitrovica), the amounts of precipitation were analyzed from five meteorological stations where two were from the category of synoptic/main climatological stations (Zemun, Sremska Mitrovica) and three from the category of precipitation (Boljevci, Hrtkovci, Brestač). All pre-specified observation objects (for monitoring of groundwater levels,
water levels on the Sava River and precipitation) are part of the observation network of the Republic Hydrometeorological Service of Serbia (RHMSS), and measurements are taken at precisely determined terms which are defined by their rule book. For the purposes of here presented results, the measured values for all analyzed parameters were taken from the database from the site of the RHMSS and from published hydrological and meteorological yearbooks of the RHMSS. General data about the measuring stations were also taken from the site of the RHMSS, and Table 1 shows the basic data about the piezometers.

<table>
<thead>
<tr>
<th>No.</th>
<th>Name-designation of piezometer</th>
<th>Cat. of piezom.</th>
<th>Elev. &quot;0&quot; of piezom. (m a.s.l.)</th>
<th>Length of construc. (m)</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Interval of observ. (day)</th>
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<tbody>
<tr>
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<td>P</td>
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<tr>
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<td>8,70</td>
<td>44°50'48&quot;</td>
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<td>3</td>
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<tr>
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<td>44°50'48&quot;</td>
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*P-individual piezometer; B-battery of piezometers

Calculation of the values of the analyzed parameters (groundwater level, water level of the Sava River and precipitation) was performed for the period 1992-2013. On the basis of daily values, the average monthly values for each year of the analyzed period were calculated, and then the average monthly values for the entire analyzed time period. In addition to these values, the analysis was conducted and the average perennial values for the annual seasons were shown for all analyzed parameters for the entire analyzed period. For the groundwater, the analysis was conducted separately for "deeper" (subartesian) aquifer on four piezometers and for "shallower" (phreatic) aquifer on ten piezometers. In the case where in the database of the RHMSS, there was no entered value for a certain term for the analyzed parameter, which was taken into account at the conducted calculations. For the period of observation, a comparative analysis of the water level of the Sava River, groundwater levels and precipitation was done by months for each year, for four annual seasons (winter, spring, summer and autumn) for the area of Podluže and summarized by months and seasons for the entire analyzed period.
Area of research and its specific features

The whole territory of the Srem is a part of a unique Pannonian sedimentary basin in which tectonic faulting and lowering the former Pannonian land did not include only the massif of Fruska Gora. In the formed tectonic depression, the semi-cohesive and non-cohesive rock masses were deposited during the Neogene, when it came to shallowing of the entire basin and the allocation of a number of shallow lakes after the Levantine-Paludine stage (Dimitrijevic et al. 1983). The formation of the recent relief began in the second half of the Pleistocene, when it came to the formation of the Danube River (by which the waters from the Pannonian area were flowing away), drying of the great lakes and the accumulation of eolian material. Changes of the climatic conditions in the glacial and interglacial periods have led to the alternation of the aeolian accumulation and fluvial erosion and accumulation.

In the area of Srem, in the alluvial plain of the Sava River, the powerful alluvial aquifer that extends from the left bank of the Sava River in the south to the loess terrace in the north was formed. In this area, the general hydrogeological conditions have been defined by the large thickness of the Neogene sediments which constitute the floor (basis) of the Quaternary formations. Over the Neogene formations, during the Quaternary, the coarse gravel and sandy sediments were firstly deposited, and then in their overlying, predominantly clay-muddy formations. Powerful alluvial aquifer in the Ravni Srem represents a natural two-layer porous environment (Nikic, 2003b; 2004). Recharge of the alluvial aquifer, that is, the main water movement takes place on the relation between the Sava River-aquifer, and the infiltration from precipitation in places where the aquifer is open toward the surface of the terrain and the flowing in of the groundwater from other aquifers. Alluvial aquifer is of a compact type and depending on the local geological relations; a semi-open or open type of the hydrogeological structure appears. In a semi-open hydrogeological structure, a subartesian aquifer was formed where the level of the aquifer put pressure on the overlying, a less permeable layer, while in the open hydrogeological structure a phreatic groundwater was formed that had a free level which fluctuated depending on the mode of recharge and drainage of the aquifer. The lower, gravel-sandy layer within the alluvial aquifer has good permeability and is usually thicker than the superficial, less permeable and thinner clay-muddy layer (Milojevic 1959). The movement of the groundwater in the lower gravel-sandy layer at a semi-open hydrogeological structure takes place in conditions of the groundwater flow under pressure and it is horizontal (the vertical component of velocity has been neglected), while in the open hydrogeological structure, the filtration of the groundwater can be directed upwards and downwards (Nikić et al. 2010). The movement of the groundwater occurs due to differences of the piezometric levels and the existence of the hydraulic gradient. Drainage of this aquifer, depending on hydrological conditions, is done towards the Sava riverbed, by evapotranspiration and exploitation over the water intake facilities (dug, drilled and Ranney wells).

In the study area, a continental type of climate is represented, which according to Rakicevic (1980) is characterized by the annual range of temperature of ≤23°C, and in the summer half of the year over 50% of the total precipitation is excreted. In general, the climate in this area is the result of distance from the sea (Adriatic) and openness to the
influence of continental air masses that circulate through the Pannonian Plain from Eastern and Northern Europe (Rakićević 1976).

RESULTS AND DISCUSSION

In favorable hydrogeological and hydrological conditions, groundwater and river water can make different forms of a hydraulic connection (Nikić 2003a). Consideration of mutual relations of groundwater and river water is a very demanding task. It reflects in the interpretation of the regime of groundwater fluctuations in a certain area depending on a number of natural and anthropogenic factors. In the area of Podlužje in the Ravni Srem, the fluctuation of the groundwater levels was discussed at the regional level as a result of geological and hydrogeological conditions within the alluvial formations, hydrological condition of the Sava River and amount of precipitation.

Taking into account the groundwater and surface water as benchmark elements, according to the basic types of mutual relations of groundwater and river water, on the basis of the conducted researches in the area of Podlužje, the existence of two main types of relations has been established: 1) direct hydraulic connection of aquifers of a free level and the river, and 2) direct hydraulic connection of subartesian aquifers and the river (Nikić 2003a). Within these two basic types of mutual relations, the groups of relations have been represented. This speaks of the complexity of the water regime in the area of Podlužje.

Figure 1. Comparative diagram of the average monthly values of the fluctuation of the groundwater levels of the shallower aquifer in the piezometer O-137 in Obrež, the water level of the Sava River in the hydrologic station of Beljin and the amount of precipitation in the synoptic station of Surčin for 1997. Legend: ── average monthly water level of the Sava River; ---- average monthly groundwater level; ‖ - monthly amount of precipitation.

In the area of Podlužje, a comparative analysis of mutual relations of the surface water of the Sava River and the groundwater of the alluvial aquifer was conducted in two water-bearing zones: 1) shallower, phreatic aquifer and, 2) deeper, subartesian aquifer. For example of the overview of a typical mutual relation of the surface water of the Sava River and the shallower aquifer (phreatic), the piezometer in Obrež (O-137) and the water
level of the Sava River in the profile of Beljin were selected for the year of 1997 (Figure 1). The graph clearly shows the dependence of the groundwater levels from the Sava River water level. It is noted that the maximum groundwater level is reached after a prolonged period of the high water level of the Sava River during the spring season. During the summer and autumn periods when the water level of the Sava River drops all the time and reaches a minimum, the level of groundwater of the shallower aquifer is also of a declining trend, but the height of the lowering of the groundwater levels is much lower.

Figure 2. Comparative diagram of the average monthly values of the fluctuation of the groundwater levels of the deeper aquifer in the piezometer NI-1 in Nikinci, the water level of the Sava River in the hydrological station of Šabac and the amount of precipitation in the synoptic station of Sremska Mitrovica for 2006. Legend: ── average monthly water level of the Sava River; ---- average monthly groundwater level; ‖ - monthly amount of precipitation.

The difference between the maximum and minimum monthly average water level of the Sava River was nearly 4 m in 1997, and the groundwater level only of about 0.5 m. Taking into account the relatively modest amounts of monthly precipitation sums in this area, a realistic conclusion is that the shallower aquifer predominantly reacts to the hydrology condition of the Sava River. However, this reaction is very slow. These points to significant retention opportunities of the water bearing environment within which the shallower aquifer was formed. This aspect is of great importance for the hygrophilic forests in the area of Podlužje. Based on display in Figure 1 it can be concluded that in the period of high water level of the Sava River in winter and shortly in spring, the river water recharges the shallower aquifer, and that in the period of low water level of the Sava River, the groundwater of the shallower aquifer recharges the Sava River discharge.

For indicating example of the overview of a mutual relation of the Sava River and the deeper aquifer (subartesian), the piezometer NI-1 in Nikinci and the water level of the Sava River in the profile of Šabac were selected for the year of 2006 (Figure 2). In this case, a very strong dependence of the fluctuation of the groundwater levels of the deeper aquifer from the Sava River water level is present. When the water level of the Sava River increases, the groundwater level increases too, and when the water level of the Sava River decreases, the groundwater level of the deeper aquifer decreases as well. It is obvious that the line of the groundwater levels follows the water level of the Sava River, but including the mitigating of the "peaks" and the existence of a certain period of time of the appearance of the maximum groundwater level in relation to the maximum water level of
the Sava River. And for the deeper aquifer we have a more pronounced fluctuation of the Sava River water level, which is about 4.1 m, and for the groundwater, the fluctuation between the maximum average monthly and the minimum average monthly level is about 2.4 m. For the deeper aquifer in Podlužje, the influence of precipitation on the fluctuation of the groundwater levels does not exist. However, expressed in absolute elevations, the average monthly groundwater level of the deeper aquifer was higher than the average monthly water level of the Sava River during the whole year of 2006. It is a realistic assumption that this is the result of complex local hydrogeological conditions. The level of the deeper aquifer and the water level of the Sava River, shown in Figure 2, clearly points that the deeper aquifer continuously charges the Sava River discharge. This leads to its very respectable water potential. In addition, in terms of the hygrophilic forests in the area of Podlužje, the significance of the subartesian aquifer is reflected in the fact that due to the existence of the hydrostatic pressure (which acts on the seam less permeable layer), this water contributes to the recharge of the shallower aquifer.

Figure 3. For the area of Podlužje, a comparative diagram of the average monthly fluctuations of the levels of shallower and deeper waters of the alluvial aquifer, the water level of the Sava River and precipitation for the period 1992-2013. Legend: ── average monthly water level of the Sava River; --- average monthly level of deeper groundwater; •••• average monthly level of shallower water; || average monthly amount of precipitation; grey area - vegetation period.

For the period 1992-2013, for the area of Podlužje, Figure 3 shows the average monthly level of the shallow groundwater (phreatic) and deep (subartesian) aquifer, the water level of the Sava River and precipitation. And for this 21-year analyzed period, as well as for the previous one year periods, there is an obvious correlation of the surface water and the groundwater, that is, the existence of a direct hydraulic connection between the alluvial aquifer and the water of the Sava River. This point to the significance of the groundwater in terms of its use for purposes of the hygrophilic forests during the dry season. Thanks to the existence of a hydraulic connection between the deeper and shallower water through less permeable layers within the alluvial formations of the Sava River, these waters in certain hydrogeological conditions may be available to the hygrophilic forests during the vegetational season.

Figure 4 presents a mutual relation between groundwater and river water by the annual seasons for the period 1992-2013 in the area of Podlužje. And this graph expresses a mutual dependence of surface water and groundwater. During the winter season and a
half of the spring season, a higher level of surface water and groundwater is noticeable, and the trend of decrease and the lower water levels during the second half of spring, summer and autumn. However, it is important that groundwater is of a milder and much slower trend of a decrease in levels during the recession period. Therefore, groundwater gains in importance precisely when water is most needed for the vegetation during the dry season.

![Figure 4](image-url)

Figure 4. For the area of Podlužje, a comparative diagram of the average seasonal fluctuations of the levels of shallower and deeper waters of the alluvial aquifer, the water level of the Sava River and precipitation for the period 1992-2013. Legend: — average seasonal water level of the Sava River; -- average seasonal level of deeper groundwater; •••• average seasonal level of shallower water; ‖ average monthly amount of precipitation.

On the basis of the data used in this study and the obtained results, it cannot be said with certainty what will be the future of the hygrophilic forests in the area of Podlužje. Taking into account that the groundwater of the alluvial aquifer from this area is used more intensively (and in the future will be used even more), and for other purposes (water supply, irrigation), the need and the necessity of allocating priorities for its use will come to the fore. This upcoming issue should be particularly seen in the light of climate change.

The obtained research results indicate that groundwater in favorable hydrological conditions may contribute to the improvement of the water regime and thus improve the functional stability of the hygrophilic forests in the area of Podlužje in the Ravni Srem. In this way, it can be actively contributed to the survival and progress of the hygrophilic forests in these areas.

**CONCLUSION**

Favourable natural conditions and a wealth of different types of water resources (surface water and groundwater and precipitation) have enabled the emergence of high-quality hygrophilic forests in Podlužje, that is, in the whole area of the Ravni Srem. The construction of the embankment for the defense of the flood waters of the Sava River and other melioration facilities, have led to a significant disruption of the hydrological situation in this area.
Thanks to the favorable hydrological and hydrogeological conditions, a powerful alluvial aquifer in the alluvial formations of the Sava River exists. Waters of this aquifer are in a hydraulic connection with waters of the Sava River and because of that, there is a certain mutual connection. For shallower, phreatic aquifer which level is closer to the surface of the terrain, a small fluctuation of the groundwater level is characterized. Due to relatively low depth of the level from the surface of the terrain, water is available to the root system of the hygrophilic forests in the favorable hydrological conditions. For the subartesian aquifer, which is slightly deeper than the surface of the terrain, a considerable quantitative abundance of groundwater and the existence of hydrostatic pressure are characterized and hence it contributes to recharge the shallower aquifer through less permeable layers, while the atmospheric precipitation have no direct impact on the fluctuation of levels of this aquifer.

Obtained dependencies can be in function of prognosis of the groundwater levels in parts of the alluvial plain of the Sava River, which is defended from the flood waters. This contributes to the successful management of hygrophilic forests in terms of allocation of the area on which, depending on the local hydrogeological conditions, can be possible to achieve, naturally or through hydromeliorational facilities, better availability of groundwater for the purpose of functional stability of these forests in the explored area.

Available data on the dynamics of groundwater and its amounts are general, but with a strong positive signal that groundwater of the alluvial aquifer may be in function of the hygrophilic forests and successful forestry production both in the present and in the future. Therefore, special attention to the area that is under the hygrophilic forests in Podlužje and even throughout the Ravni Srem should be given to the establishment of a functional observation network of groundwater stations.

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