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Anthropogenic impact on the groundwater regime: Case study of the Velika Morava alluvium

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Антропогенно въздействие върху режима на подземните води: алувиален хоризонт на Велика Морава

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Abstract. The Velika Morava River originates at the junction of the Južna Morava and Zapadna Morava at the town of Stalać in Serbia. It is 185 km long and empties into the Danube. The Velika Morava River Basin occupies a land area of 37 444 km^2. The river flows through central Serbia, which features the most fertile land and the highest population density in the country. Public water supply in this region of Serbia relies on groundwater formed in alluvial sediments of the Velika Morava. Both industry and agriculture are well developed. There is intensive sand and gravel mining along the riverbanks, which has deepened the river channel by as much as 4 m and lowered water surface elevations at Ljubičevski Most. Given that, there is a hydraulic connection between groundwater and the Velika Morava, water levels in wells have also declined. The paper analyzes the elevations of the Velika Morava's water surface and the water table.

Keywords: hydrology, surface water regime, groundwater regime, the Velika Morava River.

Introduction

Sand and gravel mining is an important industry that supports the development of society through the construction of residential and commercial spaces, infrastructure, and the like. According to Serbia's Register of Water Resources, 180 river sediment mining approvals were issued between 2009 and 2016. The majority, about 110, were related to the Velika Morava River Basin. Sand and gravel are mined from the Danube and the Sava largely from watercraft, and from the Drina, the Velika Morava, the Južna Morava, and the Zapadna Morava mostly by dredging the banks or from the banks (https://nationalgeographic.rs). Given that, these resources have ceased to be renewable because of reservoirs built along the upstream reaches of the rivers or their significant tributaries, no over-exploitation of sand and gravel should be taking place. Mining should not affect the regime of the river from which sand and gravel are excavated, nor should it affect the regional biocenosis or the ecological status of

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the river and its environs. This is possible only if mining is controlled and undertaken within the bounds of available reserves. However, if mining is unchecked or illegal, the consequences to surface water and groundwater resources are unfathomable. Such sand and gravel mining alters river courses and thus endangers fish spawning sites, kilometers-long abandoned gravel pits are used for illegal dumping of waste and become potential sources of infection and pollution, and so on (https://www.politika.rs).

Study area

The Velika (Eng. Greater) Morava originates at the junction of the Južna (South) Morava and the Zapadna (West) Morava near the town of Stalać. The Velika Morava empties into the Danube at the city of Smederevo. It is 185 km long from its origin to mouth. When its longer constituent tributary, the Zapadna Morava, is added, the overall length is 493 km. However, the most distant river source within the Velika Morava River Basin is that of the Ibar (the largest tributary of the Zapadna Morava), such that the hydrographic length of the Velika Morava is about 550 km. The basin area of the Velika Morava, along with its constituent rivers, is 37 444 km^2 or 42% of Serbia's territory. As such, it is Serbia's main drainage area. The tributaries on the right side of the valley are the Jovanovačka Reka, the Crnica, the Ravanica and the Resava, and on the left side the Jezava with the Ralja, the Lugomir, the Belica, the Osaonica, the Lepenica, the Rača and the Jasenica (Mladenović et al., 2022).

A good hydraulic connection between groundwater and the Velika Morava has resulted in the formation of considerable groundwater reserves in the intergranular medium of the alluvium. At high river discharges, when the water level of the river is at higher elevations than the water table, the aquifer is recharged on account of surface water. Moreover, vice-versa, when river stages are lower than the water table, groundwater recharges the river (during dry periods) (Vakanjac, 2018).

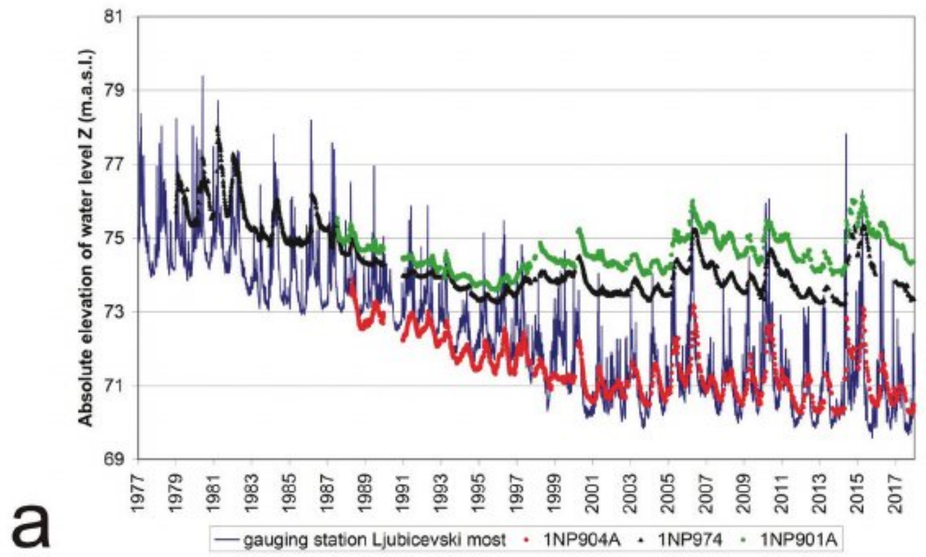
The data used for the study were obtained from the Hydrometeorological Service of the Republic of Serbia, which monitors streams (stages, discharges, cross-sections, sediment load, etc.) and groundwater (depth-to-groundwater in observation wells and certain groundwater quality parameters). River stages are generally observed using staff gauges and limnigraphs, along with automated digital instruments installed in some places. Groundwater is monitored by means of water level meters in observation wells every five to ten days. Diver dataloggers were installed in some of the observation wells in 2002. Information about the observation wells and gauging stations at Ljubičevski Most (Eng. Ljubičevo Bridge) and Žabarski Most (Žabari Bridge) are available on the website of the National Hydrometeorological Service.

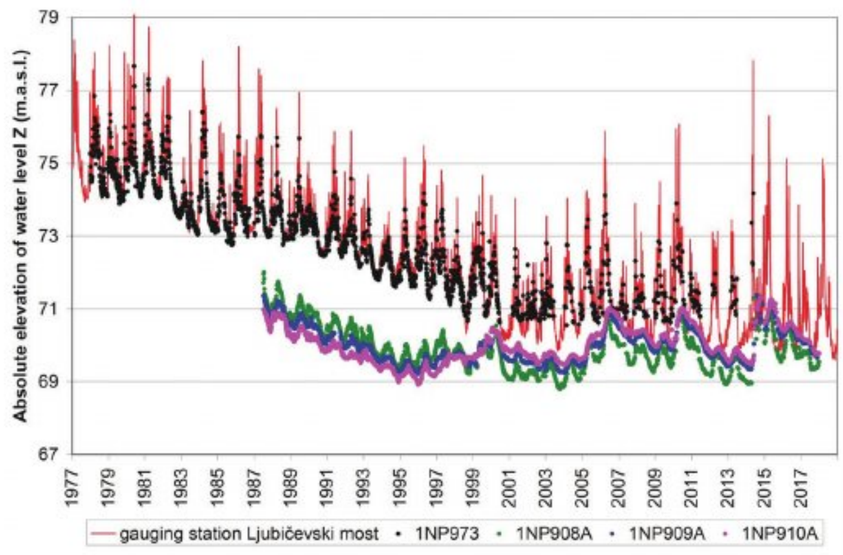
Results, discussion, and conclusion

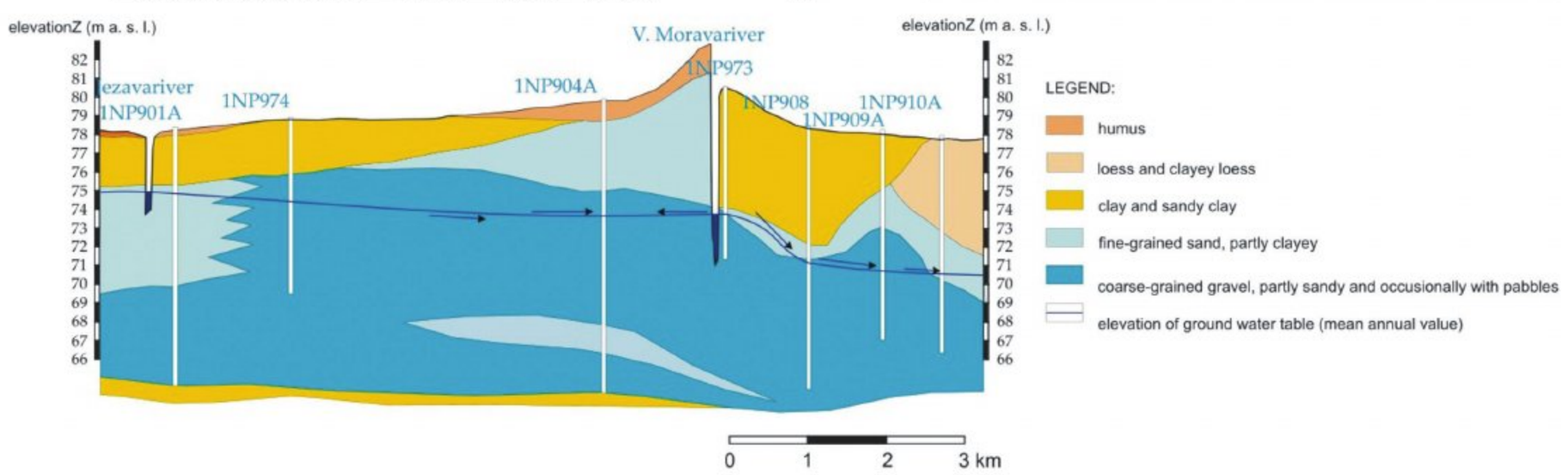
Based on the comparative plots of surface water and groundwater elevations (Figs. 1a, b), the water level of the Velika Morava began to decline in the early 1980's (by up to 1 m), due to deepening of the river channel. The reason was the construction of the section of highway E75 from Batočina to Ćuprija, which required some re-alignment of the Velika Morava channel. Consequently, an old gauging station was relocated in 1980. However, a more significant water level decline was registered in the 1990's, caused by unchecked or illegal sand and gravel excavation around Ljubičevski Most, by as much as 4 m (Figs. 1a, b). Deepening of the river channel caused the water table to drop. Observation wells up to 10 m deep and those very close to the river (< 100 m) dried out for most of the year and were consequently decommissioned in 2014 (e.g., observation well 1NP973). In addition to the declining water table, which reduced groundwater reserves, the groundwater nitrate load became an issue because at one point it was much higher than the threshold value (above 120 mg/l). As a result, the water supply source "Ključ", which services the public water supply system of the city of Požarevac, had to be closed. It resumed operation after the nitrate problem was resolved by the construction of artificial recharge ponds, which lowered nitrate concentrations to below the threshold value (to about 20 mg/l) (Stepanović et al., 2022).

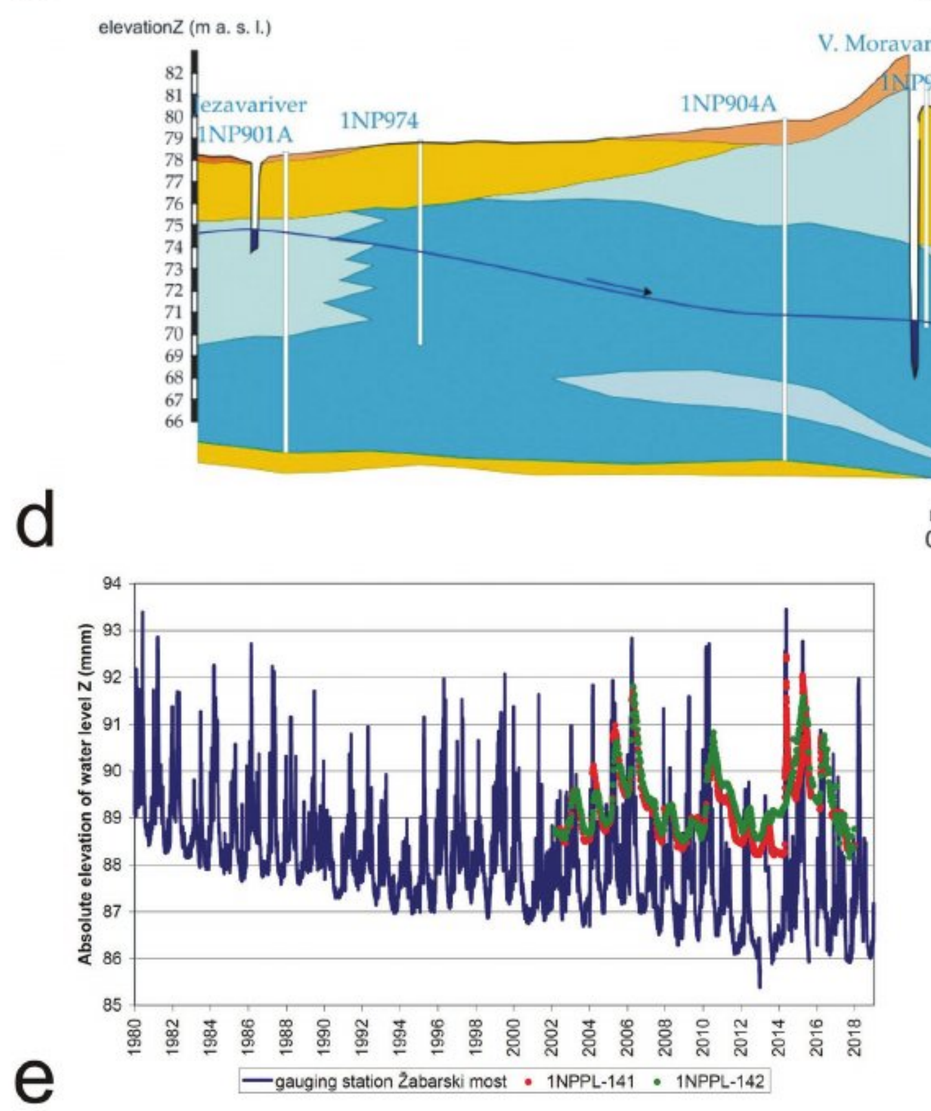
Along the right bank, the river recharged the aquifer throughout the year until 1990. As the river channel deepened in the 1990's, its course became altered after the year 2000 and groundwater recharged the river at low and medium discharges. More precisely, the highest groundwater levels were recorded in the most distant observation wells (Fig. 1b).

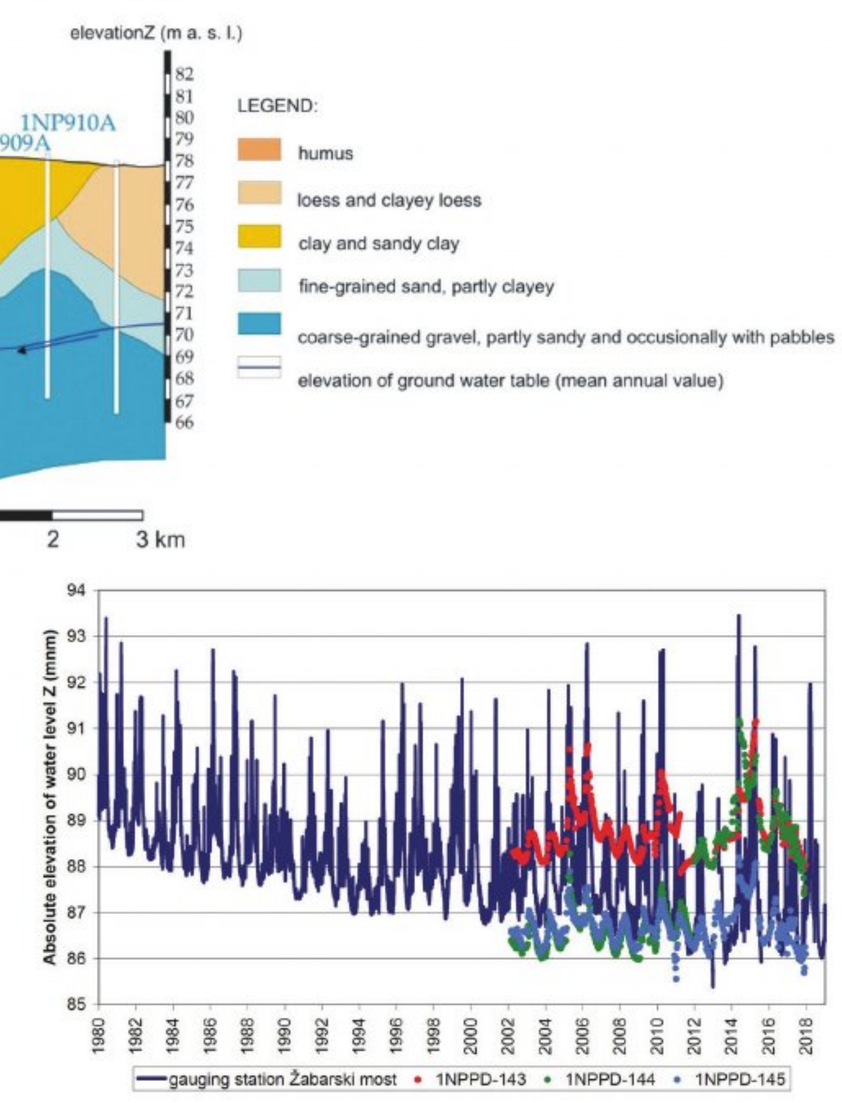
On the left bank, the part of the aquifer adjacent to the Velika Morava used to be recharged by the river. After the river channel deepened, the groundwater levels in the observation wells close to the river indicated that the direction of groundwater flow had changed. Specifically, groundwater recharged the river at low and medium discharges. On the other hand, distant observation wells registered the water table below the water level of the river only at extremely high discharges. The reason for this is the Jezava River, which flows parallel to the Velika Morava (left bank), at a distance of about 2 km. The Jezava recharges groundwater in that area. Another











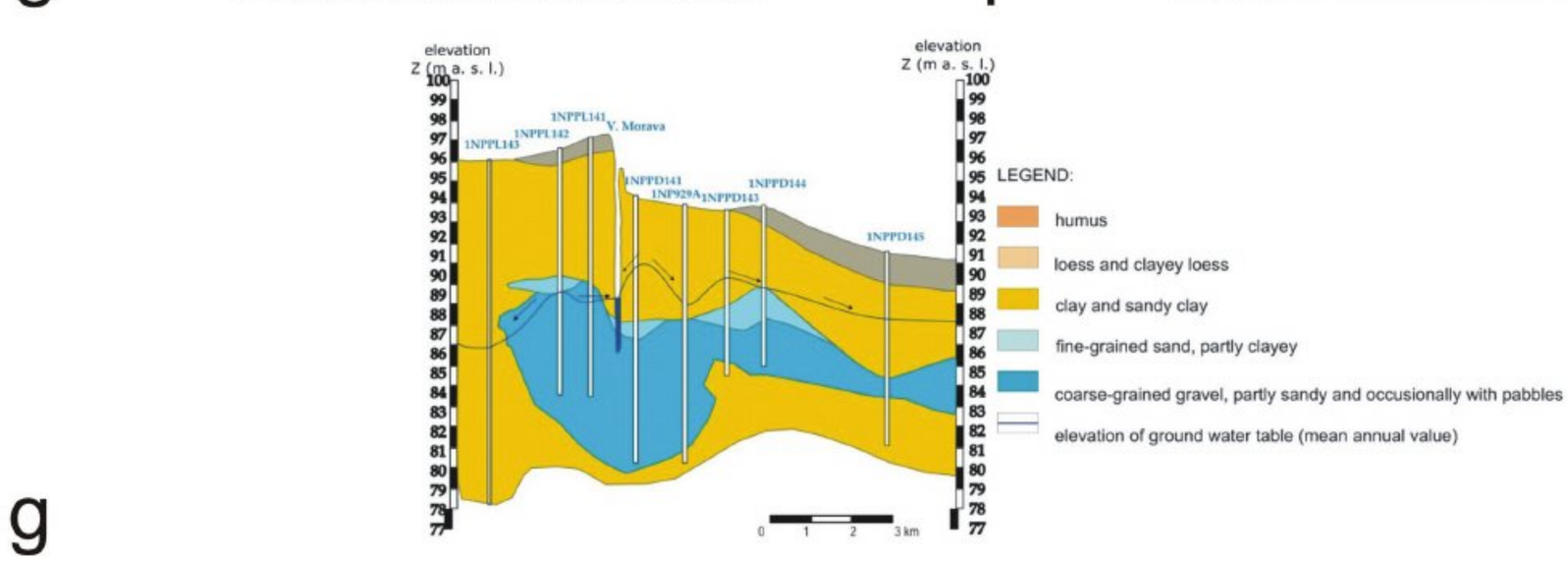


Fig. 1. (*a*) Comparative plots of the Velika Morava's water surface elevations at Ljubičevski Most and groundwater levels in observation wells along the left bank and (*b*) the right bank (Mladenovic et al., 2022); (*c*) hydrogeological section through the Ljubičevski Most area in 1988 (modified Kresojević et al., 2003); (*d*) hydrogeological section through the Ljubičevski Most area in 2008; (*e*) comparative plots of water surface elevations at Žabarski Most and groundwater levels in observation wells at Velika Plana – Žabari, left bank and (*f*) right bank (Mladenovic et al., 2023); and (*g*) hydrogeological section through the Žabarski Most area in 2008

characteristic change is in the groundwater flow velocity after the 1990's, due to larger gradients (Fig. 1a). Figure 1c is a section perpendicular to the gauging station at Ljubičevski Most, showing the groundwater flow direction before the 1990's. Figure 1d shows that direction after the 1990's. The values indicated are annual averages for 1998 and 2008.

The gauging station of Velika Plana-Žabari at Žabarski Most, on the left side of the valley, reflects a complex effect of the Jasenica River on the groundwater in the Velika Morava alluvium (Figs. 1e, f). Groundwater level varies as a function of river stage. At low and medium discharges, groundwater flows from the upland to the river and vice-versa at high discharges. The distance of the observation wells to the river affects the correlation coefficients. The most distant observation well exhibits the strongest correlation. The presence of an uppermost clayey layer, 8 to 9 m thick, tends to impair the hydraulic connection between the Velika Morava and the groundwater. This layer is shown in Fig. 1g. The situation on the right side of the valley is different. The correlation coefficients of the more distant observation wells are higher. The water levels in these wells indicate that they have been generally lower than the stages of the Velika Morava for a long time. Figure 1g is a section at the pertinent gauging station, along with annual averages for 2008.

This paper reflects only some of the analyses conducted with the data collected on the Velika Morava from the gauging stations at Ljubičevski Most and Žabarski Most, as well as pertinent observation wells. More gauging stations are covered by Mladenović et al. (2023). All those gauging stations indicate no anthropogenic impact along the upstream reach of the Velika Morava (e.g., station at Velika Plana-Žabari). However, the gauging station at Ljubičevski Most provides evidence of the effect of sand and gravel mining.

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