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Research paper

# Impacts of deep groundwater monitoring wells on the management of deep geothermal Pre-Neogene aquifers in the Mura-Zala Basin, Northeastern Slovenia

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ABSTRACT

Management of deep geothermal resources in Slovenia is very complex because of the depth of the geothermal aquifers. In this study we have developed a conceptual model for the management of deep geothermal aquifers in Northeastern Slovenia, which has turned out to be much more complex. Evolution of the problems that occurred when developing a conceptual model are based on previous and newly collected data of geothermal waters of Pre-Neogene aquifers in Mura-Zala Basin. Isotope and chemical compositions of groundwater revealed that mixing of deep groundwater in the Pre-Neogene aquifers occurs in exploitation wells at Veržej and Petišovci.

According to the history of explotation well construction it is difficult to identify the real cause of mixing of groundwater and of pressure lowering with increasing depth inside wells. Monitoring of groundwater wells in the Mura-Zala Basin based only on exploitation and not monitoring the wells may lead to misleading results. Groundwater mixing is thought to be due either to inadequate construction of exploitation wells in the past, which were and still are used for monitoring or to changed hydrodynamic conditions resulting from uncontrolled exploitation of groundwater without reinjection rate. In this respect, new construction of multilayer monitoring wells in the future is needed, which could lead to more reliable monitoring results, better control of better control of groundwater resources and the hydrogeological system of the Pre-Neogene aquifers.

## 1. Introduction

The Pre-Neogene aquifers in the Mura-Zala Basin (NE Slovenia) have been rich in low-enthalpy geothermal resources. The main problem that we face today is that geothermal water from Pre-Neogene aquifers has been exploited a lot, leading to its possible critical condition in the future exploitation of non-return water into the aquifer. Management monitoring of geothermal wells based only on data of exploitation and not on monitoring wells, which could give misleading results. Measurement of the geochemical parameters of the groundwater of exploitation wells in the research area is related to the hydrogeological characteristics and compositions of the hydrogeochemical conceptual model.

The main threat to geothermal resources is the constant exploitation that leads to changes in groundwater levels and the quality of groundwater. However, the prediction of the groundwater effects and groundwater quality is complex. In order to predict long-term responses to groundwater of Pre-Neogene aquifers, thus leading to groundwater management a good hydrogeochemical conceptual model leading to reliable results is needed. Such models are used for screening of the groundwater utilization, flow and the groundwater management of aquifers. Furthermore, within the EU Water Framework Directive, the Groundwater Directive 2006/118/EC has been developed in response to the requirements of Article 17 which deals with groundwater and covers several different steps for achieving good quantitative and chemical status. It is only possible to achieve such a status of groundwater by new multilayer monitoring of wells at the research area.

A good conceptual hydrogeochemical model is thus an increasingly important tool for management of geothermal water resources as well as for assessment of their exploitation on the long term. To elaborate a conceptual model, a comprehensive study of all hydrogeological and hydrogeochemical parameters of the Pre-Neogene aquifers from well

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constructed multilayer monitoring wells in the Mura-Zala Basin is required.

Groundwater samples from fifteen deep exploitation wells were collected and compared from Mura and Lendava formation aquifer systems over various time periods from 1991 to 2011 in the past and present research from 2011 to 2013. We have collected isotope and chemical compositions of groundwater revealing possible locations where mixing of groundwater could occur.

We have focused solely on exploitation wells where there is a great change in hydrogeochemistry in groundwaters, thus suggesting that mixing of groundwaters mostly occurs at Veržej, Petišovci and Moravci. Mineralisation of groundwaters increases with depth, relying on the good quality of groundwater coming from Mura formation aquifers and, a little less from good groundwater extracted from the Lendava formation aquifer system. Based on existing hydrogeochemical data it is generally known that groundwaters are recharged from the northwestern direction and that regional groundwater flows from the west. This is difficult to confirm within this study and remains a question. Pooled by hydrogeochemical data from previous and present studies reflect in this study suggest an inflow of water from an alluvial aquifer near the surface, which is opposite to regional groundwater flow and to possible pressure lowering with depth inside geothermal aquifers. Results of exploitation wells also suggest, that deep groundwater mixing in the Pre-Neogene aquifers occurs in exploitation wells at Veržej,and Petošovci. We concluded that such mixing is the probable cause of inadequate construction of exploitation wells in the past or due to changed hydrodynamic conditions as a consequence of uncontrolled exploitation of groundwater without reinjection rate. To identify the real cause appropriately constructed of multilayer monitoring wells for better management of geothermal aquifers at the research area are needed.

## 2. Background and methods

### 2.1. Study area

#### 2.1.1. The geological setting of the study area

The geological and tectonic structure of Slovenia is very complicated (Figs. 1 and 2). The Alps and the Dinarides were formed during the collision of these two great tectonic plates (Alps and Dinarides) that have continued to form from the Jurassic to the present. Folding and thrusting occurred in several phases and numerous deep fracture zones were formed in localized areas, enabling thermal water to circulate to the surface from depths of several kilometres, providing zones that were sufficiently permeable (Lenkey et al., 2002). A zone with such characteristics is the transitional region between the Pannonian region and the southern Alps, called the Mura Depression. The Mura Depression forms a part of the much larger Zala basin, which extends from southwestern Hungary to northern Croatia and belongs to the widespread system of Pannonian basins. Although formation of the Mura Depression began early in the Carpathian stage of the Tertiary age, the main subsidence occurred during the Late Pliocene and Quaternary, where it was closely related to the tectonic activity, producing deep-seated strike-slip faults (HasenhuÈttla et al., 2008; Pleničar et al., 1968). Two of the latter are particularly important: the northeast–southwest trending Radgona fault in the north and the east–west trending Ptuj-Ljutomer fault in the central part. Along the faults, two Depressions developed (Radgona and Ptuj-Ljutomer Depressions), separated by the horst of the Murska Sobota massif (Figs. 1 and 2).

The Mura- Zala Basin is filled with clastic sediments of the Tertiary, Pliocene, Miocene and Quaternary ages (Table 1). Tectonic units are differentiated according to type, age and thickness of the Tertiary sediments and tectonic conditions. First, three horizons were identified (Turk, 1993; Kralj and Kralj, 2000b), including the pre-Tertiary basement, the Mesozoic Lendava basement and the upper Lendava horizon. The litostratigraphic classification of Mura-Zala Basin aquifers has been updated and the aquifers subdivided into five formations (Lapajne, 2006, 2007; Lapajne et al., 2011; Nádor et al., 2012; Szőcz et al., 2013; Rman, 2013 and references therein; Rman, 2014) (Table 1): Ptuj-Grad, Mura, Lendava, Haloze & Špilje and Mesozoic basement carbonate rocks. In our research, we have focussed on three hydrogeological formations: Mura, Lendava and Haloze & Špilje.

The Haloze & Špilje Formation was formed with the mid-Miocene (Badenian) transgression. Shallow marine deposits prevailed throughout the mid-Miocene (Badenian and Sramatian) on the Murska Sobota masiff. In the Late Miocene (Pannonian), the area turned into a vast lake system. Rivers from the rising Eastern Alps continuously filled the sub-basins with prograding deltas (Šrman et al., 2015).

Lendava Formation comprises turbidites fed from the prograding delta, which are overlaid by fine-grained deposits. Well-permeable coarse-grained turbiditic sandstone and limestone of the Špilje and Lendava formations store significant quantities of oil and gas (HasenhuÈttla et al., 2008) and oil-prone thermal water (Kralj and Kralj, 2000).

The Mura formation aquifers consist of interconnected lenses of nonlithified sands of high permeability, while the Lendava formation aquifers are less productive and consist of lithified sediments, mostly sandstones of lower permeability (Doorenval et al., 2000; Vižintin et al., 2005; Kraljić et al., 2008).

#### 2.1.2. The hydrogeological setting of the study area

The study area Ptuj-Ljutomer Depression is located in the eastern part of the Mura-Zala Basin, with an area of 652 $km^2$, (NE) (Figs. 1 and 2). The Mura-Zala Basin developed as a result of the Lower to Middle Miocene (Rman, 2014), covered with the Sarmatian sea, except for the Murska Sobota massif. Withdrawal of the Sarmatian sea caused erosion (Pezdič, 1991). In the Pannonian age, the area was covered by the Pannonian sea. Rivers from the Eastern Alps continuously filled basins and sub-basins with prograding deltas. Pannonian transgression led to submersion of the Murska Sobota massif (Šrman et al., 2015). In the deeper parts of the Pannonian sea, where fine grained sediments were deposited, the low salt content waters were captured in their pores. As these sediments, had very low permeability, overpressure zones allowed them to develop under the weight of younger sediments. The groundwater could, and still can, escape towards the lower potential levels of the upper hydrogeological units, transporting groundwater of a higher salt content (Lapajne et al., 2011).

Sediments of the Murska Sobota massif decline towards the syncline, so there is a possibility that the hydrocarbons are accumulated throughout the littoral area of the Badenian sea, south-west. It was assumed therefore that Badenian sandstones also contain oil or gas. Not only Badenian, but Sarmatian and Pannonian sediments are also assumed to contain gas and oil. In these sediments (Pleničar et al., 1968), geothermal water is also present, which proves that these sediments have great porosity and permeability. Porosity and permeability vary with depth and geological structure. The best aquifers, with great hydraulic conductivity and porosity, are located at between 800 and 1200 m, in the Mura formation, while in deeper parts, porosity is lower.

The groundwater system of the Mura-Zala Basin is one of the largest and deepest depressions of the Pannonian basin system, extending from NE Slovenia to SW Hungary (Jelen and Rifelj, 2011). It is characterized by rich low-enthalpy water resources, coming mostly from Mura formation aquifers. The latter are constituted of Pre-Neogene sand, gravel, clay, silt and silty sand, with a high hydraulic conductivity, and may span from $1 * 10^{-3}$ to $8.79 * 10^{-5}$ m/s (László, 2002; Vižintin et al., 2005a, 2007).

The basement rock aquifers were tasted at a few locations, but not exploited. They contain little thermal water. Hydrologically, the Pre-Neogene aquifers are divided into three hydrogeological systems: Mura, Lendava and Haloze & Špilje formation aquifers (Fig. 3(a–c)), where groundwaters are mainly extracted from the Mura formation aquifers. The lowermost (Haloze & Špilje formation) aquifer system (Fig. 3(c)) is