POSSIBILITIES FOR MANAGED AQUIFER RECHARGE CONSIDERING LOCAL GROUNDWATER FLOW PROCESSES IN THE DANUBE-TISZA INTERFLUVE AREA

THESES OF PHD DISSERTATION

by

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1. Introduction and objectives

In the field of water management, one of the most promising ways of adapting to climate change is Managed Aquifer Recharge (MAR), which can be described as the purposeful recharge of water to aquifers for subsequent recovery or environmental benefit (Dillon et al. 2009). In Hungary, in addition to surface water retention, enhanced groundwater recharge is expected to play an increasingly important role in water management (OVF, 2022).

In the Danube-Tisza Interfluve (DTI) area, groundwater levels have declined significantly, due to climate change and human activities, which has also affected the groundwater-dependent ecosystems (GDEs) in the area (Kovács et al., 2017). Several plans have been developed to address the water scarcity, mainly through large-scale technical investments (e.g., Danube-Tisza canal; Orlóci 2003). The common feature of these large-scale plans is that they attempt to handle the problem from a surface water recharge perspective, ignoring the natural characteristics and the groundwater flow systems of the area. In this area the question of water replenishment needs to be approached from a different perspective, considering hydrogeological aspects as well. This requires the investigation of local-scale water recharge methods based on the retention and storage of local water resources. Taking local conditions into account, rainwater harvesting from rooftops (RRWH) combined with infiltration into shallow wells (RRWH-SW) could be a favourable MAR method in the DTI area in several aspects.

Considering i) the previous regional scale studies of groundwater flow systems in the Danube-Tisza Interfluve area (e.g., Mádl-Szőnyi and Tóth, 2009); ii) the case studies on rooftop rainwater harvesting coupled with shallow infiltration wells (e.g., Pavelic et al, 2022); and iii) the lack of investigation of groundwater flow from a MAR perspective, the main objectives of the doctoral thesis were the followings:

1. assessing local groundwater flow characteristics in the study area from a hydraulic and hydrochemical perspective,
2. characterising the seasonal water level and hydrochemical variations in the study area,
3. studying the operation of an RRWH-SW system (developed in the DTI area) for two hydrological years in a porous aquifer i) to characterise the quantitative and qualitative potential of the method, ii) to determine its environmental impact, with special regards to possible groundwater contamination, and iii) to analyse changes in infiltration efficiency,
4. evaluating the effects of groundwater table inclination and other parameters on infiltration-based MAR efficiency in a simple half-basin for the restoration of GDEs and testing of the results along a semi-theoretical section between Kerekegyháza and Lake Kondor.

2. Applied methods

I used archive well data recorded at the time of construction (from SZTFH) to investigate the groundwater flow conditions in the study area. I used the available water level (71 wells in total) and hydrochemical parameters of the wells (34 wells in total) to prepare pressure-elevation profiles, tomographic fluid potential maps, concentration-elevation diagrams, and a Piper diagram.

I carried out seasonal measurements in shallow dug wells in the vicinity of Kerekegyháza to evaluate the temporal variability of groundwater levels and water quality. Out of the 17 dug wells, identified during the first survey, seven were suitable for water level measurements, of which only three were suitable for water sampling. In case of these wells, I measured the physicochemical parameters of the water (temperature, pH, specific electrical conductivity, redox potential, dissolved oxygen) and took water samples for laboratory analysis (major ions, NO_3^-, hydrogen and oxygen stable isotopes). The three wells of the rooftop rainwater harvesting experiment were also included in the seasonal measurements.

I tested the applicability of the RRWH-SW method by continuous monitoring of a field experiment. I recorded continuous time series of water level, specific electrical conductivity, and temperature in the infiltration well (SW) and the two observation wells (P1, P2). During the seasonal measurements I evaluated major ions, trace elements, hydrogen and oxygen stable isotopes, and tritium. To interpret the results, I made additional water chemistry measurements of the precipitation, rooftop rainwater and two control wells (KE01, KE02), and I assessed the grain size distribution and organic matter content of two sediment samples, as well as the chemical composition (after total extraction and sequential leaching) of two other sediment samples. I used daily mean temperature and daily precipitation data (from OMSZ and Időkép Ltd.) and water level data from shallow monitoring wells in the area (from ADUVIZIG) to interpret the field measurements.

To evaluate the effects of groundwater table inclination and further influencing parameters (topography, model length, groundwater depth, material properties, heterogeneity, and infiltration basin parameters), I performed two-dimensional saturated-unsaturated numerical flow simulations by analysing different theoretical scenarios. Furthermore, I tested the results along a semi-theoretical section between Kerekegyháza and Lake Kondor.

3. Results, theses of the dissertation

1. Through hydraulic data processing, construction and analysis of pressure-elevation profiles and tomographic fluid potential maps, I found that **Kerekegyháza is located in a recharge area, while Lake Kondor (SW of the settlement) is located in a throughflow area**. The groundwater flow direction between them is from NE to SW, following the topography.

2. **I developed a complex methodology** both in terms of the experimental system (shallow dug well with two monitoring wells), the investigated characteristics (complex hydrological, hydraulic, thermal and water chemistry parameters) and the investigated duration (26 months) to monitor the rooftop rainwater harvesting and infiltration system, which is internationally unique and applicable elsewhere for shallow porous aquifers and rainwater infiltration into dug wells.
3. I used the long-term hydrochemical observations associated with the experiment to **demonstrate the positive effect of rooftop rainwater harvesting on shallow groundwater quality**. During the experiment, significant and sustained decrease in Mg^{2+}, Na^{+}, Cl^{-}, SO_4^{2-}, NO_3^{-} concentrations and in total dissolved solids content were achieved. By examining the contaminants in the rooftop rainwater, the well water and the sediment at the bottom of the wells and comparing them with the relevant legislation in force, I found that **rooftop rainwater was enriched in Zn, Sr, Cu, Mn, Ba and Al compared to precipitation**. However, examination of the water from the dug well and the sediment, accumulating at the bottom of the well, indicates that they are presumably bound in the sediment and therefore do not pose a significant risk to groundwater quality.
4. By comparing the hydrochemcial changes in the dug well used for the experiment and the other two dug wells used for rooftop

rainwater harvesting in the municipality, I demonstrated **the differences in the operation of the wells, which have different hydraulic connections with their environment and are characterised by different maintenance frequencies**. KE02 is mainly recharging groundwater, while SW is in dynamic contact with it; the bottom of KE01 is partially clogged due to lack of maintenance, so the infiltration process is slower. However, detailed hydrochemical measurements showed that the infiltrating water does not pose an environmental risk in any of the wells.

5. Based on the analysis of water column increases during rainfall events and subsequent infiltration curves, I found that the accumulating sediments reduced the hydraulic conductivity of the well bottom by approximately an order of magnitude. I made a recommendation for predicting the inefficiency: **if the ratio of the observed and potential water column increase is higher than 50–60% for 3 consecutive precipitation events, clogging of the well bottom can be assumed** and actions should be taken to remedy the problem.
6. Based on the scientific results and lessons learned from the experiment, **I made recommendations for the implementation of other rooftop rainwater harvesting and shallow well infiltration MAR systems at household level**, including guidelines for the design, operation, maintenance and monitoring

of the system, thus providing a basis for the proper and safe application of the RRWH-SW method.

7. Using theoretical and semi-theoretical (case study) saturated-unsaturated numerical flow simulations, I have shown the importance of groundwater table inclination for the application of managed aquifer recharge in a simple half-basin with a recharge and a discharge area. Based on the results, I developed a conceptual model on how groundwater flow and the location of recharge and discharge areas can be considered during managed aquifer recharge planning. **Water infiltration at the local recharge area indirectly causes water level increase at the local discharge area, which can sustain the groundwater-dependent ecosystem located there.** This concept offers a water management approach to achieve more efficient water retention and recharge, both in terms of water quantity and quality.

4. References

DILLON, P., PAVELIC, P., PAGE, D., BERINGEN, H., WARD, J. (2009). Managed aquifer recharge: An Introduction. Waterlines Report Series No. 13. *Australian Government National Water Commission, Canberra*, 86 p.

KOVÁCS, A. D., HOYK, E., FARKAS, J. Z. (2017). Homokhátság - a special rural area affected by aridification in the Carpathian basin, Hungary. *European Countryside, 9*(1), 29–50. https://doi.org/10.1515/euco-2017-0003

MÁDL-SZŐNYI, J., TÓTH, J. (2009). A hydrogeological type section for the Duna-Tisza Interfluve, Hungary. *Hydrogeology Journal, 17*(4), 961–980. https://doi.org/10.1007/s10040-008-0421-z

ORLÓCI, I. (2003). A Tiszát a Dunával összekötő csatorna: a Duna-Tisza csatorna. *Hidrológiai Közlöny, 83*(4), 243–250.

OVF (2022). Magyarország vízgyűjtő-gazdálkodási terve – 2021 (VGT-3). *Országos Vízügyi Főigazgatóság*, 686 p.

PAVELIC, P., HOANH, C. T., D'HAEZE, D., VINH, B. N., VIOSSANGES, M., CHUNG, D. T., ROSS, A. (2022). Evaluation of managed aquifer recharge in the Central Highlands of Vietnam. *Journal of Hydrology: Regional Studies, 44*, 101257. https://doi.org/10.1016/j.ejrh.2022.101257

5. Publications related to the PhD Dissertation

SZABÓ, Z., PEDRETTI, D., MASETTI, M., RIDAVITS, T., CSISZÁR, E., FALUS, G., PALCSU, L., MÁDL-SZŐNYI, J. (2023). Rooftop rainwater harvesting by a shallow well – Impacts and potential from a field experiment in the Danube-Tisza Interfluve, Hungary. *Groundwater for Sustainable Development, 20*, 100884. https://doi.org/10.1016/j.gsd.2022.100884

SZABÓ, Z., SZIJÁRTÓ, M., TÓTH, Á., MÁDL-SZŐNYI, J. (2023). The Significance of Groundwater Table Inclination for Nature-Based Replenishment of Groundwater-Dependent Ecosystems by Managed Aquifer Recharge. *Water, 15*(6), 1077. https://doi.org/10.3390/w15061077

SZABÓ, Z., TAHY, Á., MÁDLNÉ SZŐNYI, J. (2020). A célzott felszín alatti vízutánpótlás nemzetközi trendjei és hazai alkalmazási lehetőségei. *Hidrológiai Közlöny, 100*(4), 40–51.

6. Other publications

CZAUNER, B., ERŐSS, A., SZKOLNIKOVICS-SIMON, S., MARKÓ, Á., BAJÁK, P., TRÁSY-HAVRIL, T., SZIJÁRTÓ, M., SZABÓ Z., HEGEDŰS-CSONDOR, K., MÁDL-SZŐNYI, J. (2022). From basin-scale groundwater flow to integrated geofluid research in the Hydrogeology Research Group of Eötvös Loránd University, Hungary. *Journal of Hydrology X*, 100142. https://doi.org/10.1016/j.hydroa.2022.100142

IMIG, A., SZABÓ, Z., HALYTSIA, O., VRACHIOLI, M., KLEINERT, V., REIN, A. (2022). A review on risk assessment in managed aquifer recharge. *Integrated Environmental Assessment and Management, 18*(6), 1513–1529. https://doi.org/10.7343/as-2021-505

HAYAT, S., SZABÓ, Z., TÓTH, Á., MÁDL-SZŐNYI, J. (2021). MAR site suitability mapping for arid–semiarid regions by remote data and combined approach: A case study from Balochistan, Pakistan. Acque Sotterranee-Italian Journal of Groundwater, 10(3), 17–28. https://doi.org/10.1002/ieam.4584

7. Conference proceedings related to the PhD Dissertation

SZABÓ, Z., SZIJÁRTÓ, M., MASETTI, M., MÁDL-SZŐNYI, J. (2022). Involvement of groundwater table inclination in nature-based GDE replenishment. In: 49th IAH Congress Abstracts.

SZABÓ, Z., PEDRETTI, D., MASETTI, M., RIDAVITS, T., CSISZÁR, E., FALUS, G., PALCSU, L., MÁDL-SZŐNYI, J. (2022). Rooftop rainwater harvesting by a shallow dug well – impacts and potential from a field experiment in the Danube-Tisza Interfluve, Hungary. In: International Conference "Groundwater, key to the Sustainable Development Goals" Abstracts.

SZABÓ, Z., PEDRETTI, D., MASETTI, M., RIDAVITS, T., CSISZÁR, E., FALUS, G., PALCSU, L., SÜTŐ, V., MÁDL-SZŐNYI, J. (2022). Rooftop Rainwater Harvesting by Shallow Well Infiltration – Challenges and Opportunities. In: ISMAR11 Abstracts.

CSISZÁR, E., SZABÓ, Z., MÁDLNÉ SZŐNYI, J. (2021). Célzott felszínalatti vízpótlás (MAR) alkalmazása a hazai vízgazdálkodásban. In: Magyar Hidrológiai Társaság (MHT) XXXIX. Országos Vándorgyűlés.

CSISZÁR, E., SZABÓ, Z., MÁDLNÉ SZŐNYI, J. (2021). Célzott felszínalatti vízpótlás (MAR) alkalmazása a (csapadék)vizek helyben tartása és hasznosítása céljából. In: III. Országos Települési Csapadékvíz–gazdálkodási Konferencia, Nemzeti Közszolgálati Egyetem, Víztudományi Kar (NKE-VTK), Baja.

SZABÓ, Z., PEDRETTI, D., MASETTI, M., RIDAVITS, T., CSISZÁR, E., FALUS, G., PALCSU, L., SÜTŐ, V., MÁDLNÉ SZŐNYI, J. (2021). Sekély kutas célzott felszínalatti vízutánpótlás – Környezeti hatások és lehetőségek kísérleti vizsgálata Kerekegyházán. In: XXVII. Almássy Endre konferencia a felszín alatti vizekről – Absztrakt kötet. pp. 21–22.

SZABÓ, Z., SZIJÁRTÓ, M., MASETTI, M., PEDRETTI, D., VISNOVITZ, F., MÁDL-SZŐNYI, J. (2021). The Impact Of Topography, Geology And Local Hydrogeology On The Efficiency Of Managed Aquifer Recharge – A Case Study From The Danube-Tisza Interfluve, Hungary. In: IAH2021 Book of Abstracts. p. 165.

SZABÓ, Z., PEDRETTI, D., MASETTI, M., RIDAVITS, T., CSISZÁR, E., FALUS, G., PALCSU, L., SÜTŐ, V., MÁDL-SZŐNYI, J. (2021). The Effectivity and

Potential of Rooftop Rainwater Harvesting by Shallow Well Infiltration in Kerekegyháza, Hungary. In: Mádl-Szőnyi, J., Erhardt, I., Hohol, R. (szerk.) International Symposium on Geofluids: 7-9 July 2021 - virtual event: abstract volume. József and Erzsébet Tóth Endowed Hydrogeology Chair and Foundation, Budapest, Magyarország. p. 111.

SZABÓ, Z., PEDRETTI, D., MASETTI, M., RIDAVITS, T., CSISZÁR, E., MÁDL-SZŐNYI, J. (2021). Experimental rooftop rainwater harvesting by shallow well infiltration – A case study from the Duna-Tisza Interfluve, Hungary. In: European, Geosciences Union General Assembly EGU General Assembly 2021: Conference Abstracts. EGU General Assembly (2021). Paper: EGU21-7985.

SZABÓ, Z., PEDRETTI, D., MASETTI, M., RIDAVITS, T., CSISZÁR, E., MÁDLNÉ SZŐNYI, J. (2021). Célzott felszínalatti vízutánpótlás – Hatások és lehetőségek kísérleti vizsgálata Kerekegyházán: Experimental rooftop rainwater harvesting by shallow well infiltration in Kerekegyháza, Hungary. In: Cseresznyés, D., Király, Cs. (szerk.) XVI. Kárpát-medencei Környezettudományi Konferencia [16th Carpathian Basin Conference for Environmental Sciences]: absztrakt kötet [abstract book]. ELTE Természettudományi Kar, Budapest, Magyarország. p. 37.

SZABÓ Z., RIDAVITS, T., CSISZÁR, E., MÁDL-SZŐNYI, J. (2020). Preliminary results of Rooftop Rainwater Harvesting and shallow well infiltration pilot project in the Danube-Tisza Interfluve, Hungary. In: IWRA 2020.

MÁDL-SZŐNYI, J., SZABÓ, Z., SILVA CISNEROS, C. (2019). Recent applications and future prospects for MAR techniques in Hungary. In: 10th International Symposium on Managed Aquifer Recharge (ISMAR10) - Abstracts Book & Program. Abstract No.128.

SZABÓ, Z., MÁDLNÉ SZŐNYI, J., TAHY, Á. (2019). A célzott felszínalatti vízutánpótlás helyzete és lehetőségei hazánkban. In: Felszín, Alatti Vizekért Alapítvány (szerk.) XXVI. Almássy Endre konferencia a felszín alatti vizekről. Az előadások összefoglalói. pp. 7–8.