Evaluation of the cleaning process of groundwater following the establishment of a sewage system

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Abstract. The countries of the European Union are required to establish a sewage system in every settlement which has a population over 2000. In this Eastern-Hungarian case study the effects of the establishment of a sewage system on groundwater quality are evaluated. It was concluded that due to the contamination, which lasted several decades, the groundwater is heavily contaminated, in 85% of the wells included in the study, the concentration of NO3 was above the contamination limit of 50 mg·dm–3. Three years after the establishment of the sewage system the NO3 values significantly decreased, in 50% of the investigated wells the measured NO3 concentrations were below the limit value. The average value of 213 mg·dm–3 measured in 2013 decreased to 137 mg·dm–3, and in certain wells the rate of decrease was above 80%. By performing the Wilcoxon test (p=0.008) it was confirmed that the decrease was not accidental but was the result of the project. In 25% of the groundwater wells was not found a decrease in the concentration, a fact which is explained by the contaminant discharge of households not connected to the sewage system, and other local contaminant sources which have not been eliminated. Based on the trends observed, the cleaning process may last for years, and as such should be supported by environmental protection measures.

1. Introduction

Sewage systems are considered one of the largest sources of waste and pollutant discharge to the environment [1,2]. In Hungary, similarly to several countries in the world, the inappropriate placement and cleaning of domestic waste water originating from households leads to the contamination of groundwater resources [3,4]. In the countries of Eastern-Central Europe the most important sources of contamination are pit latrines, uninsulated sewage tanks and waste disposal sites [5]. The contaminants discharged from the above sources lead to the contamination of settlements’ water resources, as has been confirmed by several studies performed over the last few decades [6,7].

In Hungary, the establishment of the sewage water system was not carried out in parallel with the water infrastructure, and wastewater produced by households has been stored in sewage tanks. To reduce transportation costs, inhabitants intentionally constructed sewage tanks without insulation, allowing the sewage water to seep into the groundwater [8].

With its accession to the European Union in 2004, Hungary ratified the Water Framework Directive (2000/60/EC) and the Urban Wastewater Treatment Directive (271/91/EEC) which regulate the issue of contamination originating from agriculture and domestic wastewater. The latter requires the establishment of a sewage system in every settlement which has a population over 2000. Thanks to resources provided by the European Union, the establishment of the sewage system in Hungary has
accelerated over recent years; at the end of 2015 the national ratio of households connected to the sewage system was 78.8%, which, however, was still some way from the planned 90%. The ratio of households connected to the water system and the sewage system was 16% at the end of 2015 [9]. In the Northern Great Plain region – where the settlement under investigation is located – this ratio was approximately 24%.

In the settlement under investigation, the operative works started in 2013, and the sewage system was completed in 2014. In 2017, more than 90% of the households are connected to the sewage system; however, there are still households which have not fulfilled the legal requirements.

In this study the effects of the establishment of the sewage system on groundwater quality were evaluated. Our general assumption was that following the establishment of a utility sewage water system groundwater quality would improve, and three years after the elimination of the contamination the NO$_3^-$ content of the groundwater would significantly decrease below the contamination limit. To verify our hypothesis, the groundwater investigation results from before and after the establishment of the sewage system were compared. Our study can contribute to creating a more accurate picture of the environmental impact of similar investments and cleaning processes of groundwater.

2. Material and methods

2.1. Description of the study area
The settlement under investigation is located in the southwestern part of the Northern Great Plain region (figure 1). In the plain area, with an average elevation of 85-89 a.s.l, the groundwater level is 1-2 metres below the surface, as a result of which the characteristic soil types of the region were formed under the effect of water. The most frequent reference groups are Solonetz Vertisol Kastanozem and Chernozem [10]. The average precipitation is 540 mm, and the climate is Cfb, according to the Köppen classification system [11].

![Figure 1. The location of the sample and the monitoring wells.](image)

The population of the settlement is 2631 [12]. The population of the settlement has not changed significantly in the past decade [13]. According our estimations, in the 1200 households of the
settlement under investigation, on average 30-40% of the waste water, which derives from a total water volume of 120 000 m$^3$, could have seeped into the soil. This significant contaminant discharge resulted in the heavy contamination of the settlement’s groundwater resource. Thus, the dug groundwater wells are no longer used to obtain drinking water, although it is common for livestock to drink groundwater and for it to be used for irrigation.

2.2. Sampling
In this study 20 wells were investigated (figure 2). During the sampling - performed in the summers of 2013 and 2017 - the upper 1-metre water surface of the groundwater wells was sampled. The NO$_3^-$ content of the collected water samples was determined using the sodium salicylate method [14] with a spectrophotometer. The evaluation and visualization of the results were made using SPSS 22 and ArcMap 10.4.1 software.

![Figure 2. NO$_3^-$ concentrations (mg·dm$^{-3}$) of the monitoring wells in 2013 and 2017.](image)

2.3. Hypothesis testing
According to our hypothesis, the establishment of the utility sewage water system affects the NO$_3^-$ content of the groundwater, and so three years after construction the NO$_3^-$ content of the water of the wells will be significantly reduced. To test our hypothesis, statistical tests were performed using the SPSS 22 software. Since, on the basis of the Shapiro-Wilks test, one of the data sets does not show normal distribution, evaluations of any positive or negative change in the two data sets are performed using the Wilcoxon Signed Ranks Test.

3. Results
Because of the lack of sewage water management, in 2013 the groundwater wells were heavily contaminated (figure 2). Only in 15% of the 20 investigated wells (3 wells) was measured a concentration below the relevant contamination limit value of 50 mg·dm$^{-3}$ [15]. In 50% of the wells the NO$_3^-$ values were above 200 mg·dm$^{-3}$. It can be observed that in the southern parts of the settlement higher concentrations can be measured, something which can be explained by both anthropogenic and hydrogeological effects. According to our assumption, due to the North-South groundwater flow an increasing volume of household-originated sewage water mixes with the groundwater, leading to an ever-higher degree of contamination.

Evaluating the map regarding the situation in 2017, 3 years after the establishment of the sewage
system, the area is characterized by significantly lower NO$_3^-$ values (figure 2). In 2017, concentrations below the limit could be observed in 50% of the wells. The ratio of wells which were characterized by a concentration above 200 mg·dm$^{-3}$ had decreased from 50% to 25%.

The statistical tests concerning the two periods also showed a significant decrease in the NO$_3^-$ content of the wells (table 1, figure 3). The average of the 2013 values was 2013 mg·dm$^{-3}$, which decreased to 137 mg·dm$^{-3}$ by 2017. It can be seen on the boxplot figure that the 25, 50 and 75 percentage groups also show significantly lower values. The median value decreased from 202 mg·dm$^{-3}$ to 61 mg·dm$^{-3}$.

### Table 1. Descriptive statistics and wilcoxon signed ranks test.

| Year | N  | Mean  | Std. Deviation | Min. | Max. | 25th | 50th | 75th | Test Statistics |
|------|----|-------|----------------|------|------|------|------|------|----------------|
| 2013 | 20 | 213.00| 155.305        | 3    | 482  | 67.0 | 202.0| 354.5| Z -2.670        |
| 2017 | 20 | 137.40| 161.044        | 5    | 508  | 24.3 | 61.0 | 228.3| As.Sig. .008    |

**Figure 3.** Box plot of NO$_3^-$ concentrations in 2013 and 2017. The bottom and top of each box represent the lower and upper quartiles, and the line inside each box represents the median. The bottom and top bars represent the minimum and maximum concentrations.

By performing the Wilcoxon test on the two investigation periods, the significance level was determined. Given that p=0.008, the significance level is 99.2 %. It can be therefore concluded that following the establishment of the utility sewage water system the NO$_3^-$ concentrations of the groundwater wells did not improve by accident; it was the significant reduction in wastewater discharge which led to the decrease in the concentrations.

3 years after the establishment of the sewage system the NO$_3^-$ concentration significantly decreased in several wells (figure 4). In 2013, a more than 80% decrease was measured in the well with the second highest value (438 mg·dm$^{-3}$), although the NO$_3^-$ concentration of the water in this well still exceeded the contamination limit (87 mg·dm$^{-3}$). In well 19, an even larger decrease of 90% was
measured, which meant that the NO$_3^-$ content of the well – which was considered a heavily contaminated well in 2013 – decreased to significantly below the contamination limit (38 mg·dm$^{-3}$).

In 25% of the wells, however, an increase in NO$_3^-$ concentrations could be measured (figure 4). This was characteristically true of the wells with higher concentrations. The increase, however, was not extreme in any of the wells; therefore, we should rather be looking for reasons for the lack of any reduction. In the case of Well 15, which was the most contaminated, the concentration increased from 482 mg·dm$^{-3}$ to 508 mg·dm$^{-3}$. In this case the lack of any reduction can be clearly explained by the fact that the household was not connected to the sewage system, and therefore the sewage water discharging from the sewage tank continued to contaminate its environment. In the case of Well 12, the household was only connected to the sewage system in 2017; therefore, the cleaning processes had only just started. It should be noted that the increase in concentrations and the slow reductions can also be explained by the effects of other local contaminant sources in the neighboring households (pit latrines, manure heaps).

**Figure 4.** NO$_3^-$ concentrations and the connection date to the sewage system of the groundwater wells investigated.

4. Conclusions

Our investigations clearly showed that the groundwater quality of the settlements without established sewage systems significantly decreases as a result of contamination effects experienced over decades. However, other local contaminant sources and the agricultural activities taking place in the periphery of the settlements may also contribute to the significant contamination of the groundwater. After investigating the effects of the utility sewage water system set up to protect the underground water resources on groundwater quality, it was concluded that three years after the construction the groundwater quality showed a positive change, and a decrease in NO$_3^-$ concentrations can be measured. By performing the Wilcoxon test ($p=0.008$) it was confirmed with a probability of 99.2% that the decrease was not accidental but was the result of the project. In 50% of the wells, however, NO$_3^-$ concentrations were still above the relevant contamination limit, which can be explained by the presence of other local contaminant sources located in the settlement, and by the fact the connection to
the sewage water system was not complete at the time of the investigation. Based on the above, it can be concluded that the cleaning process has obviously started, but could take years to complete, and further environmental measures may be necessary to support it.

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References
[1] McArthur J M, Sikdar P K, Hoque M A and Ghosal U 2012 Waste-water impacts on groundwater: Cl/Br ratios and implications for arsenic pollution of groundwater in the Bengal Basin and Red River Basin, Vietnam Sci. Total Environ. 437 390-402
[2] Reay W G 2004 Septic tank impacts on groundwater quality and nearshore sediment nutrient flux Groundwater 42 1079-89
[3] Krügel R, Rechenburg A, Kuitha D, Fouépé A, Bellenberg S, Kangwe I M and Fomo M A 2016 Mass balance of nitrogen and potassium in urban groundwater in Central Africa, Yaounde/Cameroon Sci. Total Environ. 547 382-95
[4] Dević G, Djordjevic D and Sakan S 2014 Natural and anthropogenic factors affecting the groundwater quality in Serbia Sci. Total Environ. 468-469 933-42
[5] Szabó Gy, Bessenyei É, Hajnal A, Csige I, Szabó G, Tóth Cs, Posta J and Mester T 2016 The use of sodium to calibrate the transport modeling of water pollution in sandy formations around an uninsulated sewage disposal site Water Air Soil Pollut. 227 1-13
[6] Koda E, Miszkowska A and Sietzka A 2017 Levels of organic pollution indicators in groundwater at the old landfill and waste management site Appl. Sci. 7 638
[7] Smoroñ S 2016 Quality of shallow groundwater and manure effluents in a livestock farm J. Water Land Develop. 29 59-66
[8] Mester T, Szabó Gy, Bessenyei É, Karancsi G, Barkóczı N and Balla D 2017 The effects of uninsulated sewage tanks on groundwater: A case study in an eastern Hungarian settlement J. Water Land Develop. 33 123-9
[9] KSH Hungarian Central Statistical Office 2015 https://www.ksh.hu/docs/hun/hnk/hnk_2015.pdf
[10] Michéli E, Fuchs M, Hegymegi P and Stefanovits P 2006 Classification of the major soils of Hungary and their correlation with the world reference base for soil resources (WRB) Agrochem. Soil Sci. 55 19-28
[11] Szélescsényi Z, Breuer H, Ács F and Kozma I 2009 Biophysiological climate classifications Légkö r 54 18-24 (in Hungarian)
[12] KSH Hungarian Central Statistical Office 2017 http://www.ksh.hu/docs/hun/xstadat/xstadat _eves/i_zrk006.html#
[13] KSH Hungarian Central Statistical Office 2013 http://www.ksh.hu/docs/hun/xftp/idoszaki/nepsz 2011/nepsz_03_09_2011.pdf
[14] Literáthy P 1973 United water examination methods I. Chemical methods (in Hungarian) 1 (Budapest, Hungary: Department IV of Water Quality and Water Technology of the Water Management Scientific Research Institute) p 233
[15] 6/2009 (IV. 14.) of KvVM-EüM-FVM The Hungarian Ministries of Environment, Healthcare and Agriculture, respectively about the limit values and standard procedures to assess the pollution level, in order to protect the geological medium and groundwaters against pollution (in Hungarian)