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The effects of uninsulated sewage tanks on groundwater. A case study in an eastern Hungarian settlement

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Abstract

In our study we attempt to demonstrate the effects of uninsulated sewage tanks, which are the most important sources of contamination in settlements without sewage systems, on groundwater quality. We compared the results of measurements carried out before and one and a half years after the construction of the sewage system. We established 3 m deep monitoring wells within a 25 m radius of a sewage tank, which were then sampled, and the level of groundwater was recorded. The 3D model constructed on the basis of the saturated zone shows that the effluent wastewater formed a groundwater level dome with a height of more than 1 m. After the sewage tank was taken out of use the difference between the highest and lowest groundwater levels decreased to a few centimetres. In our study we investigated the spatial distribution of NH_4^+ (ammonium). Using the 3D model we were able to precisely determine the volume of water bodies with different levels of contamination. In an approximately 25 m^3 water body, in the immediate environment of a sewage tank in use we detected NH_4^+ at a concentration which was characteristic of undiluted wastewater (>90 $mg \cdot dm^{-3}$). After the sewage tank was taken out of use, the concentration in its immediate environment decreased by more than 50%, although almost everywhere in the modelled area concentrations were measured above the limit value. Based on the above, we can conclude that the cleaning process has started, but the complete decontamination of the groundwater will take several years.

Key words: *ammonium, groundwater contamination, groundwater level, modelling, pollution, wastewater*

INTRODUCTION

The decrease in groundwater quality has now become a global issue. The most important sources of contamination include domestic wastewater, which causes problems not only in the less-developed areas of the world, but in developed areas, as well, due to inappropriate water treatment [BANKS *et al.* 2002; HAN *et al.* 2016; JUMMA *et al.* 2012; MACHIWAL, JHA 2015; SMOROŃ 2016]. This is very dangerous because in most countries the population's drinking water supply is provided primarily from groundwater sources [BENRABAH *et al.* 2016; SHIRAZI *et al.* 2015; SZŰCS *et al.* 2015]. In Europe this proportion is 75%, but in Hungary's case, 95% of the population's drinking water is provided from groundwater sources [SZŰCS 2014].

In the rural areas of Hungary, one of the most important sources of contamination of ground and aquiferic water supplies is wastewater originating from households, the collection of which remains an unsolved problem in many places [MESTER, SZABÓ 2013; SZABÓ *et al.* 2016]. The 43% of the households with public water supply system in 1990 was not connected to the sewage system, this rate decreased to 17.7% in 2014 [KSH 2014]. Because of the lack of wastewater treatment and the expensive transportation costs, in many cases local inhabitants have chosen to build sewage storage sites in a permeable way so that the wastewater would be able to seep into the soil, resulting in the contamination of groundwater [MESTER *et al.* 2016].

In the countries of East-central Europe the pollution of groundwater is also a common problem, as evidenced by several studies. Based on the investigations carried out in Romania, ROTARU and RĂILEANU [2008] concluded that due to the lack of wastewater treatment systems in rural built-up areas the wastewater gets into the groundwater. As a consequence of this, the quality of the groundwater has significantly decreased in these areas. BACKMAN *et al.* [1997], based on their investigation in Slovakia, distinguished contaminated groundwater caused by natural and anthropogenic effects. RUDKO [2002] carried out investigations in the western part of Ukraine, during which he identified groundwater contaminated with oil and wastewater. DEVIC *et al.* [2014] investigated the water quality of 10 representative areas in Serbia. The results showed Mn, As, NO_3^-, Ni and Pb contamination, which were proven to be of anthropogenic origin. SMOROŃ [2016] distinguished heavily polluted water of the farm wells in the area of Plateau Proszowice in Poland.

In this Eastern-Hungarian case study, we attempt to demonstrate the effects of sewage tanks on the groundwater, in which we carried out investigations in the immediate environment of a sewage tank. The sewage system in the studied settlement was constructed in 2014, therefore the examined sewage tank was no longer in use. Given that we started the investigations before the sewage system had been constructed, we were able to carry out comparative examinations regarding the active and the out-of-use sewage tanks. For this purpose, we decided on two sampling dates, before and after the sewage system has been established, and we carried out comparative investigations on this basis. The aims of the study were the following: 1. To investigate the effect of the sewage tank in use on the groundwater level in the immediate environment of the sewage tank. 2. To investigate the changes occurring regarding the groundwater levels after the sewage tank had been taken out of use. 3. To demonstrate the spatial distribution of NH_4^+ (ammonium) concentrations in the immediate environment of the in-use and the out-of-use sewage tanks. 4. Using a 3D model, to estimate the volume of the water bodies contaminated with NH_4^+ regarding the given concentrations, and on this basis, identify the actual mass of NH_4^+ present in the saturated zone of the groundwater on the specified dates.

MATERIAL AND METHODS

DESCRIPTION OF THE STUDY AREA

Báránd has a population of 2,631 [KSH 2015]. The settlement is located in the eastern part of the Great Hungarian Plain, on the Nagy-Sárrét on the western part of the alluvial deposit of the Sebes-Körös River (Fig. 1).

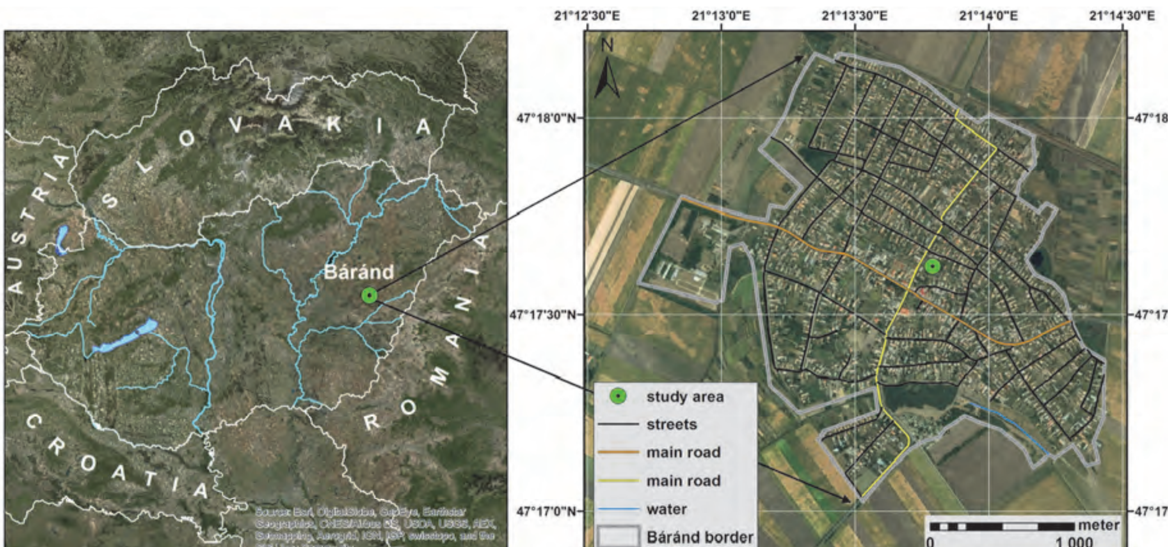

Fig. 1. Location of the study area; source: own elaboration

The small region is an alluvial plain, which was an area actively formed by rivers before water management. Characterized by an altitude of 85–89 m and a relative altitude difference of 0–3 m·km^{-2} it is classified as a flat plain. Due to the low altitude the groundwater level can be found close to the surface at a depth of 1–2 m, therefore all the soil types have been formed under the influence of water [MICHÉLI *et al.* 2006]. In the sample area the most frequent soil types were Solonetz, Vertisol, Kastenozem and Chernozem, while in the built-up area Technosol soils modified as a result of anthropogenic effects could also be identified [NOVÁK, TÓTH 2016], according to the World reference base for soil resources (WRB).

ASSIGNMENT OF SAMPLING POINTS, FIELD AND LABORATORY MEASUREMENTS

In order to analyze the effect of sewage tanks located in the settlement on the environment, we selected a sewage tank located within the boundaries of the settlement (Fig. 1), the effect of which on the groundwater has been under investigation since 2012. We established monitoring wells with a depth of 3 m in the immediate environment of the sewage tank (Fig. 2). The total depth of the monitoring wells was at least 1 m deeper than the groundwater level in every case.

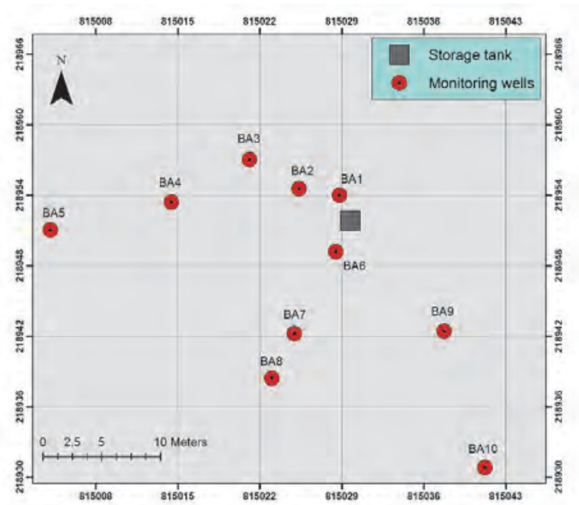

Fig. 2. Location of the monitoring wells in the study area; source: own elaboration

The water samples were collected in accordance with the MSZ 21464 [MSZ 21464:1998] standard. The water chemistry investigations were carried out in the geographical laboratory of the University of Debrecen.

Soil samples were collected from one of the monitoring wells at every 20 cm interval and their granulometric composition was determined by the Köhn pipette method [MÜLLER *et al.* 2009].

In order to identify the exact altitude of the groundwater levels, we created a digital relief map, for which we used the results of our on-site measurements performed by two Trimble S9 dual-frequency, high precision geodesic GPS (accuracy 2 cm). The interpolation of the surface was completed with a free triangular mesh.

GEOPROCESSING

The spatial geological models have been developed with the Surfer 11 and the RockWorks 14 modelling software. In order to demonstrate the groundwater levels and the NH_4^+ concentration, we created isometric maps using the kriging geostatistical method in Surfer. Using the RockWorks software we compiled the 3D model of the area, during which we also used kriging interpolation. In order to construct the 3D model of the distribution of the contaminant concentration (M), RockWorks applies the following formula:

$$M = V_{voxel} \sum_{i=1}^{n} n_{0i} c_i \tag{1}$$

where: V_{voxel} = the volume of the voxel, n_{0i} = the degree of effective porosity, c_i = the concentration value measured at the given location.

Based on the solid models created with RockWorks, we have identified the volume of the water bodies contaminated with NH_4^+ in terms of the given concentrations. Since the soil texture is loam in the investigated area, we calculated on the basis of a pore space of 45%. Then, based on the results, we identified the amount of NH_4^+ which can be found in the given water body in grams.

RESULTS

The mechanical composition of the soil plays a key role in the determination of groundwater flow. Figure 3 shows the granulometric composition of the soil in the case of the BA5 monitoring well.

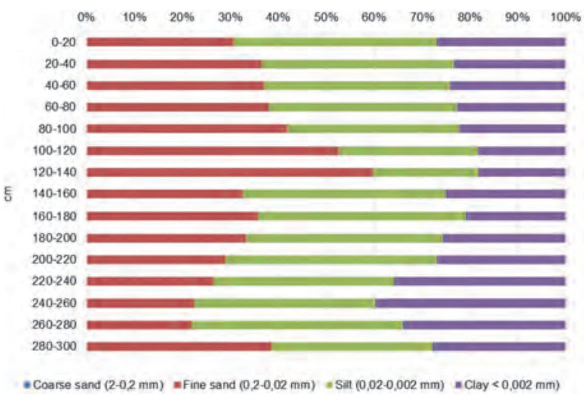

Fig. 3. Distribution of granulometric composition in the case of soil samples originating from the BA5 monitoring well; source: own elaboration

It can be seen that the soil texture is loam in all of the investigated soil layers. The Zamarin filtration coefficient values identified on the basis of the granulometric composition are very low, varying between $1.23 \cdot 10^{-7}$ and $5.20 \cdot 10^{-7}$ $m \cdot s^{-1}$ in the investigated layers [ZAMARIN 1928].

GROUNDWATER LEVEL

Based on the 3D hydrogeological model created from the simultaneous groundwater level data recorded in 2012 (Fig. 4), it can be concluded that the sewage tank significantly modifies the altitude of the groundwater level.

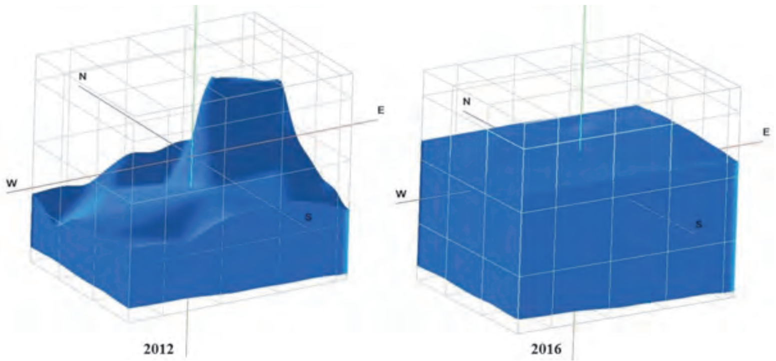

Fig. 4. The hydrogeological model of the saturated zone down to the depth of 3 m from the surface, based on the groundwater level data (2012, 2016) with 10x vertical exaggeration; source: own elaboration

The wastewater effluent from the sewage tank forms a water dome which defines the characteristics of the water flow in the area. If we compare the highest value measured in the BA6 monitoring well with the lowest value measured in the BA5 monitoring well, the difference between the groundwater levels is 117 cm. This is considered to be an extreme difference within a 25 m area for a plain area. Significant changes can be seen if we examine the 3D hydrogeological model (Fig. 4) created from the groundwater level data recorded in 2016. The water efflux from the sewage tank has stopped, therefore the water dome which formed around the sewage tank has disappeared and the greatest difference between the groundwater levels decreased to 12 cm.

SPATIAL DISTRIBUTION OF NH_4^+ CONCENTRATION

In Hungary an average of 100 $dm^3 \cdot capita^{-1} \cdot day^{-1}$ wastewater is generated, with a significant distribution [TAKÁCS 2013]. Based on the water consumption data, 116 $dm^3 \cdot capita^{-1} \cdot day^{-1}$ wastewater is generated on average in the households investigated, which means 464 $dm^3 \cdot day^{-1}$ wastewater, based on a four person household [MESTER *et al.* 2016]. Based on the above, 170 $m^3 \cdot year^{-1}$ wastewater flowed into the sewage tank from the household investigated. According to our records regarding wastewater transportation, in 2012 90 m^3 water was transported from the sewage tank in total, which means that the amount of wastewater effluent from the sewage tank was 80 m^3, making up 47% of the generated wastewater.

According to TAKÁCS [2013], the NH_4^+ concentration of domestic wastewater varies between 90 and 140 $mg \cdot dm^{-3}$. In the sewage tank investigated we measured a concentration of 115 $mg \cdot dm^{-3}$ in 2012, which corresponds to figures reported in the scientific literature. Based on the above, approximately 19,500 g NH_4^+ got into the sewage tank, from which approximately 9000 g entered the soil and the groundwater, in 2012.

By examining the isometric maps constructed on the basis of the NH_4^+ concentration values of the water samples analyzed in 2012, it can be seen that the measured NH_4^+ concentration can be 200 times higher than the contamination limit of 0.5 $mg \cdot dm^{-3}$, which indicates a recent contamination (Fig. 5). In the sewage tank we measured a value of 115 $mg \cdot dm^{-3}$, and in the BA1 monitoring well located 1 m from the sewage tank, we detected a concentration of 106 $mg \cdot dm^{-3}$. Moving away from the sewage tank, the extremely high values decrease rapidly; 5 m from the sewage tank the measured concentrations were lower than 2 $mg \cdot dm^{-3}$. The rapid decrease could be caused by multiple factors. In this loamy soil texture the NH_4^+ contamination plume could have moved primarily in vertical direction. Lateral spread could be primarily the result of diffusion. During the vertical and lateral spreading we could also count with the dilution of the pollution and the conversion of NH_4^+ to NO_2^- and NO_3^- [HEATWOLE, MCCRAY 2007].

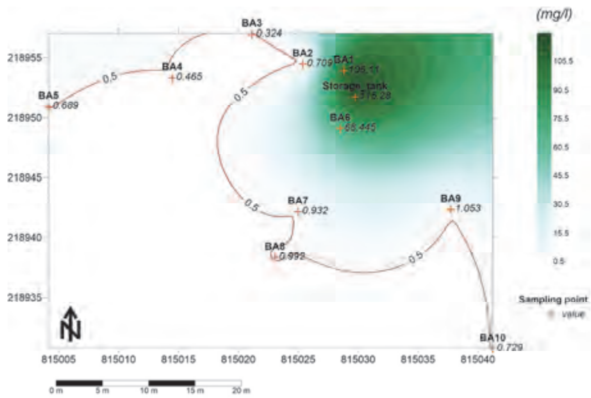

Fig. 5. NH_4^+ concentrations in the sample area in 2012; source: own elaboration

Despite the fact that the wastewater supply stopped at the end of the year 2014, the measured NH_4^+ concentration was still 35 $mg \cdot dm^{-3}$ (Fig. 6) in the sewage tank and the monitoring well located 1 m from it, which is more than 50 times the limit value, which indicates a slow nitrification. With the exception of the BA7 monitoring well, we measured concentrations higher than the contamination limit of 0.5 mg·dm^{-3} in every sampling point. The fact that the NH_4^+ concentration did not decrease to below the limit value even 1.5 years after the sewage tank had been taken out of use, which means that the cleaning process is quite slow and the studied area can still be considered a contaminated area.

The estimation of the spatial distribution and the amount of the NH_4^+ concentration was carried out using the RockWorks software (Tab. 1). Since this model carries out the kriging interpolation in 3D, it provides more reliable results regarding the entire sample area. Since during the active period of the sewage tank the wastewater efflux was uninterrupted, a water body with a volume of approximately 25 m^3 near to the sewage tank contained NH_4^+ in an amount which is characteristic of wastewater (>90 mg·dm^{-3}) (Fig. 7C).

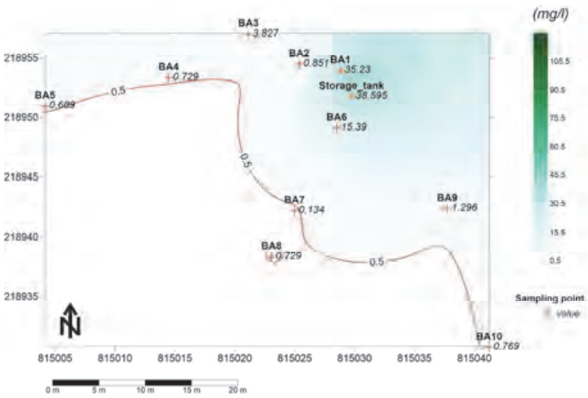

Fig. 6. NH_4^+ concentrations in the sample area in 2016; source: own elaboration

Table 1. Distribution and amount of NH_4^+ concentration in grams in 2012 and 2016 in the sample area

Concentration mg·dm^{-3}	2012		2016	
	volume of water body in the saturated zone m^3	the amount of NH_4^+ can be found in the groundwater g	volume of water body in the saturated zone m^3	the amount of NH_4^+ can be found in the groundwater g
>110	2.1	232.7	0	0
90–109.9	24.9	2 488.5	0	0
70–89.9	26.1	2 084.4	0	0
50–69.9	26.8	1 609.2	0	0
30–49.9	30.0	1 200.6	14.8	592.2
20–29.9	19.2	479.3	85.3	2 131.9
10–19.9	57.0	854.6	58.4	876.2
5–9.9	52.9	396.6	54.3	407.4
2–4.9	28.4	99.5	110.4	386.5
0.5–1.9	175.4	219.2	575.5	719.3
<0.5	172.9	43.2	120.1	30.0
In total	615.6	9 707.7	1 018.8	5 143.4

Source: own calculation.

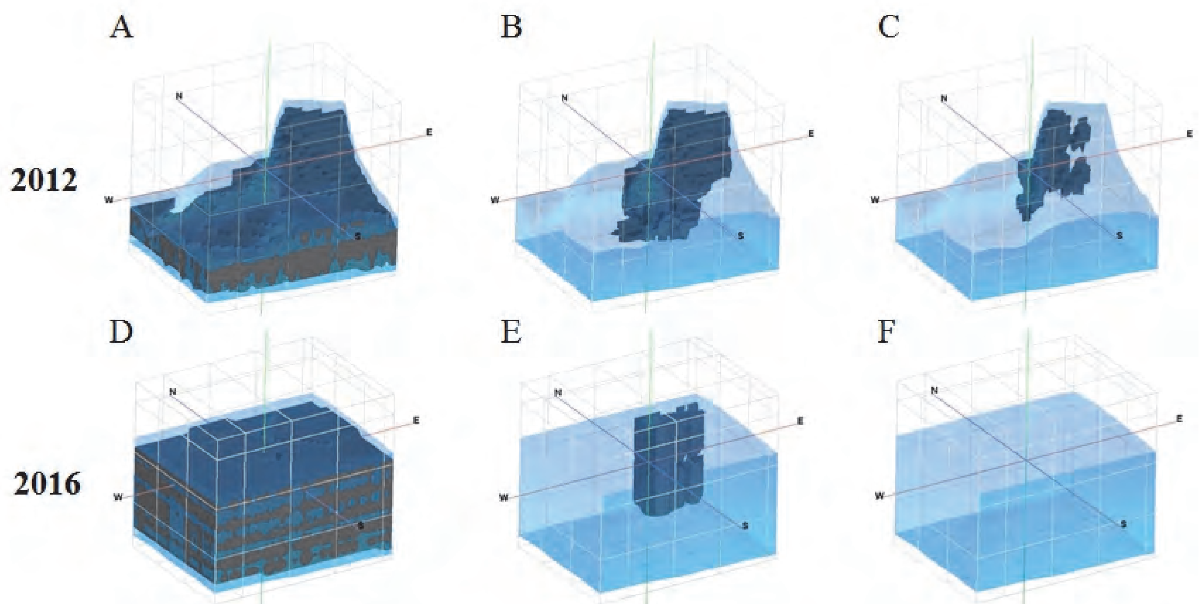

Fig. 7. Spatial distribution of NH_4^+ concentrations down to the depth of 3 m from the surface; A, D: higher than 0.5 mg·dm^{-3}, B, E: higher than 30 mg·dm^{-3}, C, F: the extension of the water body with an NH_4^+ concentration higher than 90 mg·dm^{-3}; source: own elaboration

In 2016, approximately 1.5 years after the sewage tank had gone out of use, no NH_4^+ concentration higher than 90 mg·dm^{-3} was measured in any of the sampling points, the highest value being 38.6 mg·dm^{-3}. Based on Figures 7B and 7C, it can be seen that even the volume of the water body with an NH_4^+ concentration higher than 30 mg·dm^{-3} showed a significant decrease, of more than 50% (Tab. 1).

Based on the volume values concerning the given NH_4^+ concentrations, we calculated the actual amount of NH_4^+ in the investigated water bodies (Tab. 1). It can be seen that the amount of NH_4^+ measured in the modelled zone was 9707.7 g in 2012, while this value decreased by almost 50% to 5143.4 g. Based on the above, we can conclude that during the period since the sewage tank has gone out of use a significant degree of decontamination has occurred in the investigated area, and despite the fact that extremely high values can no longer be measured (above 90 mg·dm^{-3}), in parts of the water body situated close to the sewage tank the measured NH_4^+ concentration is still many times greater than the limit value.

CONCLUSIONS

The results of our investigation clearly show that in settlements without a sewage system, the water effluent from the uninsulated sewage tanks significantly increases the groundwater level in the vicinity of the tanks. 1.5 years after the sewage tank was taken out of use the groundwater dome disappeared. Using the 3D model we were able to precisely determine the volume of water bodies with different levels of contamination. In the approximately 25 m^3 water body located in the immediate environment of a sewage tank in use we detected NH_4^+ in a concentration which is characteristic of undiluted wastewater (>90 mg·dm^{-3}). Moving away from this water body the concentrations rapidly decrease. In 80% of the monitoring wells, however, it still exceeds the contamination limit value. 1.5 years after the sewage tank had gone out of use, the NH_4^+ concentration decreased to a significant degree, and we did not measure concentrations characteristic of wastewater in any of the monitoring wells. However, in the immediate environment of the sewage tank we still measured concentrations which are many times higher than the limit value. Even though the degree of contamination still decreased rapidly away from the sewage tank, in 90% of the monitoring wells we measured a concentration above the contamination limit of 0.5 mg·dm^{-3}; therefore, the studied area can still be considered a contaminated area. Based on the above we can conclude that the cleaning process has started, but the complete decontamination of groundwater will take several years.

Despite the fact that the subject of our investigations was the effect of a specific sewage tank on groundwater, we can assume that similar processes could occurred in other households in the settlement, something which should be considered during the groundwater quality investigations in the settlement. The experiences of this case study could be useful for the investigations of groundwater of settlements with similar characteristics.

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Oddziaływania nieizolowanych zbiorników ściekowych na wody gruntowe. Przykład osiedla ze wschodnich Węgier

STRESZCZENIE

W pracy podjęto próbę wykazania wpływów nieizolowanych zbiorników ściekowych, które są głównym źródłem zanieczyszczenia w osiedlach pozbawionych kanalizacji, na jakość wód gruntowych. Porównano wyniki pomiarów prowadzonych przed i półtora roku po zbudowaniu systemu kanalizacyjnego. W promieniu 25 m od zbiornika ściekowego zainstalowano studzienki o głębokości 3 m, z których pobierano próbki i mierzono w nich poziom wód gruntowych. Na podstawie trójwymiarowego modelu zbudowanego ze znajomością strefy saturacji stwierdzono, że wypływające ścieki uformowały wypukłe zwierciadło wód gruntowych o wysokości ponad 1 m. Po wyłączeniu zbiornika ścieków z eksploatacji różnica pomiędzy najwyższym i najniższym poziomem wód gruntowych zmalała do kilku centymetrów. W przedstawionych badaniach analizowano przestrzenne rozmieszczenie jonów amonowych (NH_4^+). Stosując trójwymiarowy model można było precyzyjnie określić objętość wody o różnym stopniu zanieczyszczenia. W 25 m^3 wody w bezpośrednim otoczeniu używanego zbiornika ściekowego wykryto jony amonowe w stężeniu typowym dla nierozcieńczonych ścieków (>90 mg·dm^{-3}). Po wyłączeniu zbiornika z eksploatacji stężenie to zmalało o ponad 50%, choć niemal wszędzie nadal przekraczało dopuszczalne normy. Na podstawie uzyskanych wyników można wnioskować, że proces oczyszczania został rozpoczęty, ale całkowita dekontaminacja zajmie kilka lat.

Słowa kluczowe: *jony amonowe, modelowanie, poziom wód gruntowych, ścieki, zanieczyszczenie, zanieczyszczenie wód gruntowych*