PRIVATE WELLS AS POTENTIAL SOURCES OF HEAVY METAL EXPOSURE: A PILOT STUDY IN NORTHWEST SLOVAKIA

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SUMMARY

Objectives: The aim of this study is to analyse levels of selected heavy metals: chromium (Cr), cadmium (Cd), copper (Cu), manganese (Mn), and lead (Pb), and to recognize factors related to wells' stewardship.

Methods: The pilot study was realized in May 2018 in three villages in northwest of Slovakia. We analysed 69 water samples from private wells. The data on wells and well owners were obtained by self-administered questionnaire. The samples were analysed by atomic absorption spectroscopy with graphite furnace GF AAS (AAS GBC XplorAA 5000 with GBC GF 5000) equipped with hollow cathode lamps. Levels of heavy metals were compared with parametric values for drinking water stated in the Resolution of the Ministry of Health of the Slovak Republic No. 247/2017 Coll.

Results: The results indicated spatial variability in some heavy metal levels. Cadmium was not quantified in any sample. Copper and chromium levels were below the parametric value. Parametric values for manganese and lead were exceeded in 19 (27.5%) and 2 (2.9%) samples, respectively. Only 18 owners tested water quality. Busyness and financial cost most frequently discouraged users to carry out the water quality analysis.

Conclusions: The presence of heavy metals in well water can pose a serious public health problem, especially in rural areas without public water supply. Education on heavy metals' risks targeted at well owners could increase the awareness of the issue and minimize possible public health consequences.

Key words: drinking water, exposure, heavy metals, private well stewardship, water, well

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INTRODUCTION

The overwhelming majority of population in Europe use water from public drinking water supplies usually provided by big water companies. These distribution systems are legislatively defined as systems serving more than 50 persons or supply more than 10 cubic metres per day, but also smaller supplies if being part of any economic activity. According to the Council Directive 98/83/EC on the quality of water intended for water consumption, drinking water quality coming from these water supplies should be regularly monitored to meet all set quality standards. On the other hand, there are small water supplies, e.g. private wells, serving less than 50 persons or providing less than 10 cubic metres per day. Directive 98/83/EC considers water quality monitoring in such small water supplies as a competence of every member state (1). However, most of European countries leaves this to the owners' initiative, so the water quality monitoring can be overlooked (2, 3).

Although more than 90% of Slovak population is supplied by public water systems, private supplies (wells) are still used in numerous rural areas. It applies, for example, for rural settlements situated in hilly regions, where the extension of public water system is problematic. Moreover, some residents living in the areas with public water supply continue using wells to minimize their financial costs (4). According to the Slovak legislation, water quality monitoring in small supplies is up to their owners (3). Therefore, there is a lack of information on the water quality coming from the small supplies in Slovakia. For example, when the World Water Day (WWD) is held on 22 March every year, there are campaign activities including complimentary analysis of nitrates and nitrites in well water and professional consultancy regarding private water supplies. Unfortunately, the number of owners taking part in this campaign is low (4).

There is a wide array of potential chemical contaminants, which can be found in the well water. Heavy metals are one of the most common contaminants, present in drinking water. Their higher levels can be caused either naturally or by the anthropogenic activities (5, 6). Such an exposure, even in low level, can lead rather than to deterministic toxic effects to stochastic ones and increase the risk of numerous disorders (6, 8–13). For example, low level cadmium exposure can cause renal proteinuria (9, 10). Exposure to chronic low dose of lead is associated with anaemia, nephropathy, hypertension, reproductive toxicity, and neurobehavioural effects (13). The recent studies on manganese long-term effects reported a significant association between low level exposure and neurobehavioural performance, especially in children (8, 11). Nevertheless, it is difficult to assess the exposure to heavy metals from well water, as well as some burden of diseases attributable to drinking it. Heavy metals are usually present in well water in low levels. In addition, water is a minor source of heavy metals in comparison with other exposure media, namely food (6). Behavioural aspects, i.e., consumer's preferences, drinking habits, etc., play a crucial role as well. (14).

The study investigates levels of selected heavy metals: chromium (Cr), cadmium (Cd), copper (Cu), manganese (Mn), and lead (Pb) in wells situated in the hilly northwest rural areas of Slovakia, where frequent use of private drinking water supplies can be expected. The aim of this research is to analyse levels of Cr, Cd, Cu, Mn, and Pb, and to recognize the factors influencing private wells' stewardship among the owners.

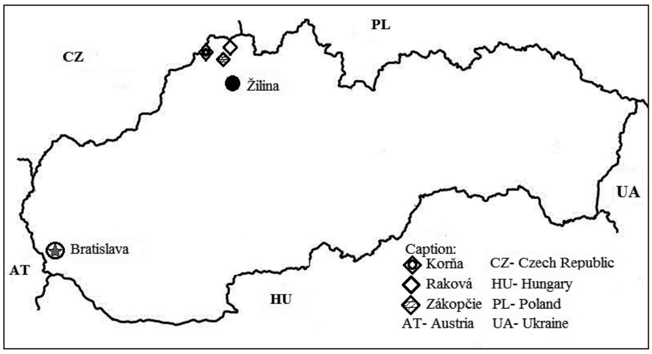

***Fig. 1.** Situation map showing localities of the selected villages (Korňa, Raková and Zákopčie).*

MATERIALS AND METHODS

Description of Study Area

The study was carried out in three villages in the Kysuce Region: Korňa, Raková and Zákopčie.

Korňa (2,057 inhabitants, population density 82 persons/km^2) is located in the mountain range called Turzov Highlands (18° 32′ 10″ E, 48° 24′ 42″ N). The village is typical for its 36 traditional settlements.

Raková (5,549 inhabitants, population 133 persons/km^2) lies on the border of Javorníky Mountains and Turzov Highlands (18° 44′ 4″ E, 49° 26′ 35″ N); except the centre of the village there are 15 smaller dispersed settlements.

Zákopčie (1,761 inhabitants, population density 59 persons/km^2) is located in the northeast part of Javorníky Mountains, in the area of right-hand tributaries of Kysuca River (18° 43′ 54″ E, 49° 24′ 21″ N). The village consists of 77 dispersed settlements (Fig. 1).

The selected region is typical for its dispersed settlements, that are situated mostly in higher elevations of valleys or mountains, not close to a community. Since 2012, when the public water system has been established, inhabitants had to use their private wells as the only drinking water supply. Nowadays, there are still some remoted dispersed settlements, which are dependent on their private wells, because of hilly relief and poor rate of return on investment in further water supply expansion.

Selected villages are situated in the northwest of Slovakia, close to Polish border on the north and Czech on the west (Fig. 1). Geotechnical profile includes flysch layers, made up of sandstones, claystones and clay shales. Northwest wind prevails here. However, there are no significant industrial pollution sources in the region. On the other hand, air pollution by selected heavy metals from the nearby Moravian-Silesian Region cannot be omitted.

Sample Collection and Analysis

In April 2018, we sent an email to the local authorities (either mayors or local activists in Korňa) to ask well owners for participation in our project. Later, in May 2018, following the participants consent, we started collecting data. Well owners received sterile polyethylene bottles, complementary questionnaires and participant information leaflet from the local authorities. Both the sample container and the questionnaire were labelled with the same identification code. To guarantee the owners' privacy, the samples were taken by the owners themselves with the assistance and supervision of office workers in Raková, mayor in Zákopčie and activists in Korňa. All the representatives were educated and trained how to sample well water.

We collected 69 water samples coming from the dug and drilled private wells. Water samples for chemical analysis were collected in 250 ml sterile polyethylene bottles. Immediately before sample taking, water was run for 1 to 5 minutes and then bottles were rinsed three times with the water. If the water was sampled directly from the well, the string was attached to the bottle neck. Subsequently, we filled up the bottle to 2/3 of the maximum volume, shake and poured them out. Then, we fully filled the bottle with the water (up to the edge). All the samples were transported to the laboratory within 24 hours.

In the laboratory, 67–69% trace metal grade HNO_3 was added into the samples (500 µl HNO_3 in 100 ml of well water) and afterwards each water sample was filtered by cellulose filtration paper. The levels of Cr, Cd, Cu, Mn, and Pb were determined by atomic absorption spectroscopy with graphite furnace GF AAS (AAS GBC XplorAA 5000 with GBC GF 5000) equipped with hollow cathode lamps. The sample volume required for analysis was 20 µl. Argon was used for the inert gas flow and deuterium lamp was used for a background correction. The chemicals for the experiments were in a high purity grade. We used ultrapure water type 1 (UPV H_2O) with resistance 18.2 MΩ · cm for the blank, standards preparations and water dilutions. All the containers needed for the laboratory analysis were washed up with ultrapure water, subsequently sank in a trace metal grade HNO_3 for a day and then rinsed with UPV H_2O. The calibration solutions standards were acidified by trace metal grade HNO_3 to the same levels of concentration as the samples. Table 1 shows specific parameters of the heavy metals' analysis.

The measured levels of heavy metals in well water were complemented by data coming from self-administered questionnaire. The pilot test of the questionnaire was realized among 30 well owners from Horný Kalník village. The questionnaire collected information on numbers of potentially exposed persons in household, well design and its construction characteristics, well maintenance frequency, well water use, and the water quality monitoring. Well owners filled the questionnaire during the sampling process and returned it with the water sample. After the pilot study we applied the same methods for water sampling and

Table 1. Specific parameters for analysis of selected heavy metals

Element	Hollow cathode lamp (wavelength, current)	Standard concentration	Limit of detection	Limit of quantification	Modifier
Cd	228.8 nm, 3 mA	2.6 µg/L	0.1 µg/L	0.3 µg/L	(NH4)3PO4
Cr	357.9 nm, 6 mA	16 µg/L	0.3 µg/L	0.9 µg/L	
Cu	175.0 nm, 4 mA	24 µg/L	0.4 µg/L	1.0 µg/L	
Mn	279.5 nm, 5 mA	6 µl/l	0.1 µg/L	0.4 µg/L	
Pb	217.0 nm, 5 mA	26 µl/l	1.2 µg/L	4.0 µg/L	1% Pd

laboratory analysis. Original questionnaire from the pilot study was used except minor syntax corrections. Finally, we collected 69 questionnaires altogether from Korňa, Raková and Zákopčie.

Levels of heavy metals were compared with parametric values (PV) stated in the Resolution of the Ministry of Health of the Slovak Republic No. 247/2017 Coll. This Resolution corresponds with the Annex I to Directive 98/83/EC on the quality of water intended for human consumption. In addition, levels of manganese were also compared with PV 200 µg/L given in the Resolution. This PV applies for the areas with high natural occurrence of manganese in the earth crust.

Statistical analysis was performed using Epi InfoTM version 7.2. software. Descriptive analysis was used to calculate means, medians, standard deviations (SD), and minimum and maximum levels. Heavy metal levels were presented as means. The results were graphically expressed by bar charts.

RESULTS

We analysed 69 samples of the well water and the questionnaires, 24 of them from Korňa, 15 from Raková and 30 from Zákopčie. The total number of potentially exposed persons included 260 individuals, 34 of them were children. Median initial year of private well use was 1980. Most of the water samples (87.0%) originated from dug wells. Only 20.3% of the wells used some filtration system for water treatment and 13 wells were not built in accordance with distance requirements stated in the Slovak Technical Norm STN 75 5115.

Well water was used for drinking in 56 households, the most frequently in Zákopčie (86.7%), followed by Korňa (83.3%) and Raková (66.7%). More than three quarters of households reported to drink well water in combination with commercially distributed bottled water. However, the well water was predominantly used for drinking in the whole area, 36 well owners rarely or never inspected their private water system. Besides drinking, there were 5 households using water for watering their gardens and 2 for personal hygiene (Table 2).

Considering laboratory analysis, cadmium levels were as low as being quantified in one sample. Chromium levels higher than limit of quantification (LOQ) were found only in 6 (8.7%) samples and there was no sample exceeding parametric value for chromium. We quantified copper in every tested sample. Maximum copper level 641.6 µg/L was found in the sample from Korňa, the

Table 2. Selected characteristics of private well water supply (N = 69)

Characteristics	Categories	Location			Total (n = 69) n (%)
		Korňa (n = 24) n (%)	Raková (n = 15) n (%)	Zákopčie (n = 30) n (%)	
Type of well	Drilled	7 (29.2)	1 (6.7)	1 (3.3)	9 (13.0)
	Dug	17 (70.8)	14 (93.3)	29 (96.7)	60 (87.0)
Well water components	Filtration system	6 (25.0)	0 (0.0)	8 (22.9)	14 (20.3)
Inspection of water well system	Annually	11 (45.8)	3 (20.0)	16 (53.3)	30 (43.5)
	Every few years	5 (20.8)	5 (33.3)	10 (33.3)	20 (29.0)
	Never	5 (20.8)	7 (46.7)	4 (13.3)	16 (23.2)
Water testing	At least once except of WWD testing*	5 (20.8)	2 (13.3)	11 (36.7)	18 (20.1)
	WWD testing	3 (12.5)	0 (0.0)	4 (13.3)	7 (10.1)
Well construction	Maintaining distance requirements	23 (95.8)	11 (73.3)	22 (73.3)	56 (81.2)
Well water use	Drinking	20 (83.3)	10 (66.7)	26 (86.7)	56 (81.2)
	Well water only	7 (29.2)	3 (20.0)	3 (10.0)	13 (18.8)
	Bottled and well water	13 (54.2)	7 (46.7)	23 (76.7)	43 (62.3)
	Watering	3 (12.5)	0 (0.0)	2 (6.7)	5 (7.2)
	Personal hygiene	1 (4.2)	0 (0.0)	1 (3.3)	2 (2.9)

*WWD testing – World Water Day testing (levels of nitrate) minimum level 4.2 µg/L in the sample from Zákopčie. Copper PV was not exceeded in any sample. We quantified manganese in every sample as well. Average manganese level in Korňa was 130.7 µg/L, 113.7 µg/L in Raková and 18.7 µg/L in Zákopčie. The highest maximum level, but also the minimum one came from Raková. Manganese PV 50 µg/L was exceeded in 19 (27.5%) samples. Moreover, 7 (10.1%) samples even exceeded the Slovak PV for manganese (200 µg/L), four of them were used for drinking. The samples with the lowest manganese levels came from Zákopčie, where 24 (80.0%) samples were under PV. Lead was quantified in 42 (60.9%) samples. The highest average lead level (8.1 µg/L) was found in Korňa. There were also two samples significantly exceeding lead PV (20.1 µg/L and 20.0 µg/L). Considering lead, the lowest levels were found in the samples from Zákopčie with average lead level 4.7 µg/L (Table 3).

Only 18 owners declared at least one water quality testing other than WWD testing. Most of tested wells came from Zákopčie, the least from Raková. The most common factor affecting need motivation for water quality analysis was curiosity, followed by health and safety. On the other hand, busyness and financial cost discouraged users to carry out the water quality analysis (Fig. 2). The WWD testing was performed only in 7 cases. The main reason for non-participation was a lack of information about the campaign (Fig. 3).

DISCUSSION

Our analysis demonstrated potential risks related to small water supplies and possible exposure to heavy metals among inhabitants living in selected settlements in the northwest part of Slovakia. Although we selected only limited amount of well owners, the results indicate that private wells are still commonly used in such type of households; even though the public water infrastructure has been already expanding. Paradoxically, majority of residents in the selected area used water in their households for drinking. It could be explained by the specific location of chosen villages consisting of small, dispersed settlements at higher mountainous locations disabling further extension of water supply infrastructure (15).

Dug wells pose a dominant portion of small water supplies in the region, because they can obtain water from less permeable

Table 3. *Levels of selected heavy metals in private wells*

	Cr			Cu			Mn			Pb		
	Korňa	Raková	Zákopčie	Korňa	Raková	Zákopčie	Korňa	Raková	Zákopčie	Korňa	Raková	Zákopčie
>LOQ (No)[1]	2	3	1	24	15	30	24	15	30	11	14	17
Average (µg/L)	1.5	1.2	1.6	57.1	32.4	14.3	130.7	113.7	18.7	8.1	5.2	4.7
Geometric mean (µg/L)	1.5	1.2	–	18.8	15.8	11.3	21.9	18.2	8.9	6.8	5.0	4.6
Median (µg/L)	1.5	1.2	–	13.3	13.7	10.0	8.9	9.6	5.9	5.3	4.6	4.5
Minimum (µg/L)	1.3	0.9	–	5.4	4.2	4.6	2.9	0.6	2.7	4.4	4.1	2.5
Maximum (µg/L)	1.7	1.4	–	641.6	248.9	80.8	805.0	974.0	88.6	20.1	9.8	7.1
>PV (No)[2]	–	–	–	–	–	–	9	5	5	2	–	–

Cr – chromium; Cu – copper; Mn – manganese; Pb – lead; LOQ – limit of quantification; PV – parametric value; [1]number of samples above LOQ; [2]number of samples exceeding PV given in the Resolution of the Ministry of Health of Slovak Republic No. 247/2017 Coll.

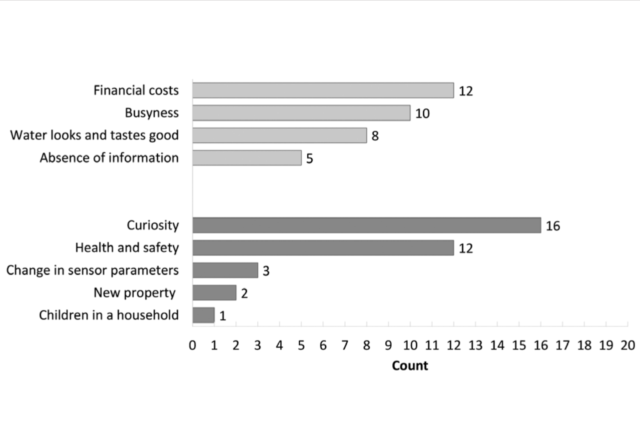

Fig. 2. *Main reasons for and against testing well water quality (N=69).*

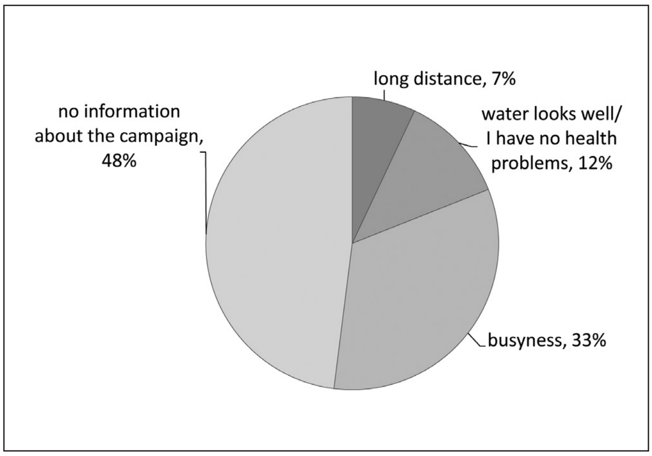

Fig. 3. *Reasons for non-participation in WWD.*

materials, what makes them favourable for the hilly Kysuce Region (16). Despite this advantage, the dug wells are shallow with a strong seasonal variation in water levels and there is a high probability of water contamination, especially from surface soil levels (17).

On the other hand, ground water quality largely depends on geochemical properties of the area (18, 19). The Kysuce Region, especially its western part, is typical for higher levels of manganese in groundwater and its spatial variability (16). As the results showed, we noticed manganese exceeding PV for drinking water in 19 wells. We also found a spatial variability in manganese levels within samples coming from different villages. Although copper levels in well water were below PV, average levels of this element were higher than previously published copper levels coming from this region (20). Because there has not been documented any natural copper contamination so far, the effect of anthropogenic activities such as using fertilizers or copper-based fungicides can be expected (21). Although the water is not generally considered as common lead exposure medium, the analysis confirmed exceeded PV in two samples from Korňa. These findings can be at least partially explained by several studies describing the corrosion of water system infrastructure and use of lead-bearing plumbing components as main reasons leading to increased lead levels (22). Agricultural activities could play an important role as well (6). On the other hand, except of the samples exceeding PV, all lead levels in samples from Korňa were higher than in other two villages. In the past, there were several natural oil seeps in Korňa (16, 23). Crude oil can enhance soil by lead and then with the contribution of other factors leach into the well water (24). Except for the abovementioned factors and their combination, we can also speculate about the wind flow coming from the nearby industrial Silesian Region (25, 26). To clarify these hypothesis, further environmental monitoring should be realized.

In the recent years, some studies from North America documented an increasing interest in understanding the well owners' behaviour (7, 27, 28). Unfortunately, there is a lack of information from Europe. Our results show heavy metals as frequent contaminants of well water and indicate underestimation of the problem by the respective owners. Although most households have used well water, water system did not include any filter to remove mechanical impurities or reduce the levels of some chemical contaminants. This is in accordance with previously published studies demonstrating that most owners maintain wells minimally and often are unlikely to regularly test their well water quality (7, 18, 27). Well owners in our sample most frequently declared curiosity as a reason for water quality testing, similarly as in the study from Wisconsin (27). On the other hand, the study from Canada noticed this reason as less common (28). Despite of well-known high sensitivity of children to low levels of heavy metals and related effects (10, 12) only one in 69 owners stated this as a reason for water testing. This finding indicates considerable gaps in health awareness and a need for better information and education.

Despite of the World Water Day campaign annually held in Slovakia, only 7 owners took the opportunity to test their water and more than a half of them did not know about this. Again, we can see a knowledge gap and a need for more effective promotion of the campaign. We believe that if the well owners knew about the campaign and its activities, it could increase awareness of private water systems, improve stewardship including more appropriate treatment and maintenance of wells and regular water quality testing.

There are some limitations to our study. Firstly, it is recommended to collect samples by trained researcher in order to minimize potential method bias. In our pilot study, we decided to take samples as well as to collect questionnaires by representatives, to keep well owners' privacy as our priority. According to Slovak legislation, each private water supply (except of hand-dug well) is considered as a hydraulic construction. It means, that the owner must obtain a building permission by the respective authorities in order to use his/her private well. In Slovakia, most of owners use their private well without this authorisation so there could be some owners' concerns to participate in the study. This potential barrier could also have an impact on our sample randomization. Therefore, we decided to ask owners for the participation in the study by mayors and to take samples only from owners, who decided to participate in the study. Although chosen method strategy could potentially influence our selections, we suppose this would not significantly bias our results and respective interpretations. Therefore, our findings provide an important insight into the issue because of a relatively large sample size and clear pointing out the public health aspect of it.

CONCLUSION

Our results showed, that despite availability of public water supplies in Slovakia, there are still areas with a frequent use of private wells and potential risk of exposure to heavy metals. The analysis identified manganese as the most frequent and potentially risky heavy metal present in well water. There were also two samples significantly exceeding lead PV. Our results showed a spatial variability in heavy metal levels. Therefore, we suppose small water supplies as a potential serious public health problem requiring attention. Appropriate targeted education of well owners could increase the awareness of the issue and minimize possible public health consequences.

Acknowledgements

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Conflict of Interests

None declared

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