

Environmental burdens in Šurany – groundwater pollution by chlorinated aliphatic hydrocarbons

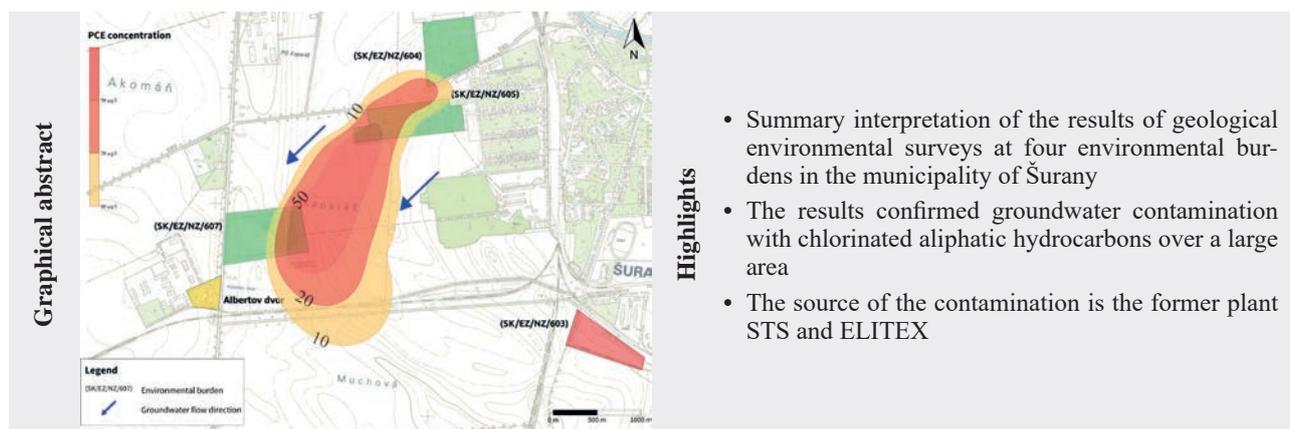
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Abstract: In the past, the town of Šurany was a local center of industrial production, which resulted in the existence of five environmental burdens. Industry was associated with the intensive use of hazardous substances. In 2022, geological surveys of the environment were carried out on three environmental burdens in the town's cadastral area (the former sugar mill, the former CALEX plant and the municipal solid waste dump). The survey results were processed together with the results of a detailed geological survey of the STS and ELITEX site (2015) and a supplementary survey of the CALEX plant (2023). The aim was to identify various groups of pollutants in the soil and groundwater (petroleum hydrocarbons, PAHs, BTEX, CAHs, metals). Geological work confirmed massive groundwater contamination with chlorinated aliphatic hydrocarbons in the southwestern part of the town. The results show that the main source of contamination is the former STS and ELITEX site, from which the contamination spreads downgradient with groundwater flow. The maximum concentrations of pollution were very high (cis-1,2-dichloroethene 2,810 $\mu\text{g.L}^{-1}$, trichloroethene 2,970 $\mu\text{g.L}^{-1}$, tetrachloroethene 247 $\mu\text{g.L}^{-1}$). Unlike the other sites investigated, vinyl chloride was also present in the groundwater (max 168 $\mu\text{g.L}^{-1}$). High concentrations of CAHs were identified 500 m downgradient the STS and ELITEX sites in groundwater at a municipal solid waste dump (cis-1,2-dichloroethene 469 $\mu\text{g.L}^{-1}$, trichloroethene 842 $\mu\text{g.L}^{-1}$, tetrachloroethene 125 $\mu\text{g.L}^{-1}$).

Key words: Groundwater, Contamination, Chlorinated Aliphatic Hydrocarbons, Environmental Burden, Šurany



Introduction

Chlorinated aliphatic hydrocarbons (CAHs) are among the most widespread groundwater pollutants. This is due to their long-term use (since the beginning of the 20th century) and their wide range of applications, particularly in industrial degreasing and dry cleaning of clothing (Booij et al., 1992; Doherty, 2000). CAHs belong to dense non-aqueous phase liquids (DNAPLs), substances with density higher than water (Kram et al., 2001; Pankow & Cherry, 1996). The most commonly used are trichloroethene (TCE) and tetrachloroethene (PCE) (He et al., 2021). The first mention of their negative impact on groundwater

quality dates back to 1949 (Lyne & McLachlan, 1949). Dichloroethene (DCE) and PCE isomers are classified as probable carcinogens according to the US EPA, while vinyl chloride (VC) and TCE are classified as confirmed carcinogens (ATSDR, 2019, 2024). DNAPLs migrate vertically through the unsaturated zone in a similar way to light non-aqueous phase liquids from the point of leakage. They gradually descend through the aquifer until they reach an impermeable layer (e.g. clay), where they may accumulate in depressions (Huling & Weaver, 1991; Rubin et al., 1998). CAHs, as water-soluble pollutants can easily spread and contaminate aquifers in large areas (Hyldegaard & Ottosen, 2021). DNAPLs can persist in

groundwater for several decades and act as an perennial source of contamination (Essaid et al., 2015). Remediation is due to their nature complicated and requires a detailed study of bedrock properties.

The aim of the study is to assess the spread of pollution from several possible sources located close to each other in the western part of the town of Šurany. Despite the facilities being shut down for more than 30 years, groundwater pollution persists in high concentrations. Monitoring the development of concentrations in groundwater in space and time is the starting point for the implementation of remediation activities.

Characteristics of the area

The town of Šurany is located in the Danube Lowland, in the southern part of Slovakia (Nové Zámky District). In the past, the town was a center of industrial and food production, employing people from the wider area. The town was home to the oldest sugar mill in Central Europe (founded in 1854), the ELITEX plant (approx. 2,200–2,600 employees) produced components for cars and later for knitting machines. At the CALEX plant, approx. 300 employees produced parts for refrigeration equipment (Šutka et al., 2008). The entire town of Šurany has approximately 10,000 inhabitants. After the

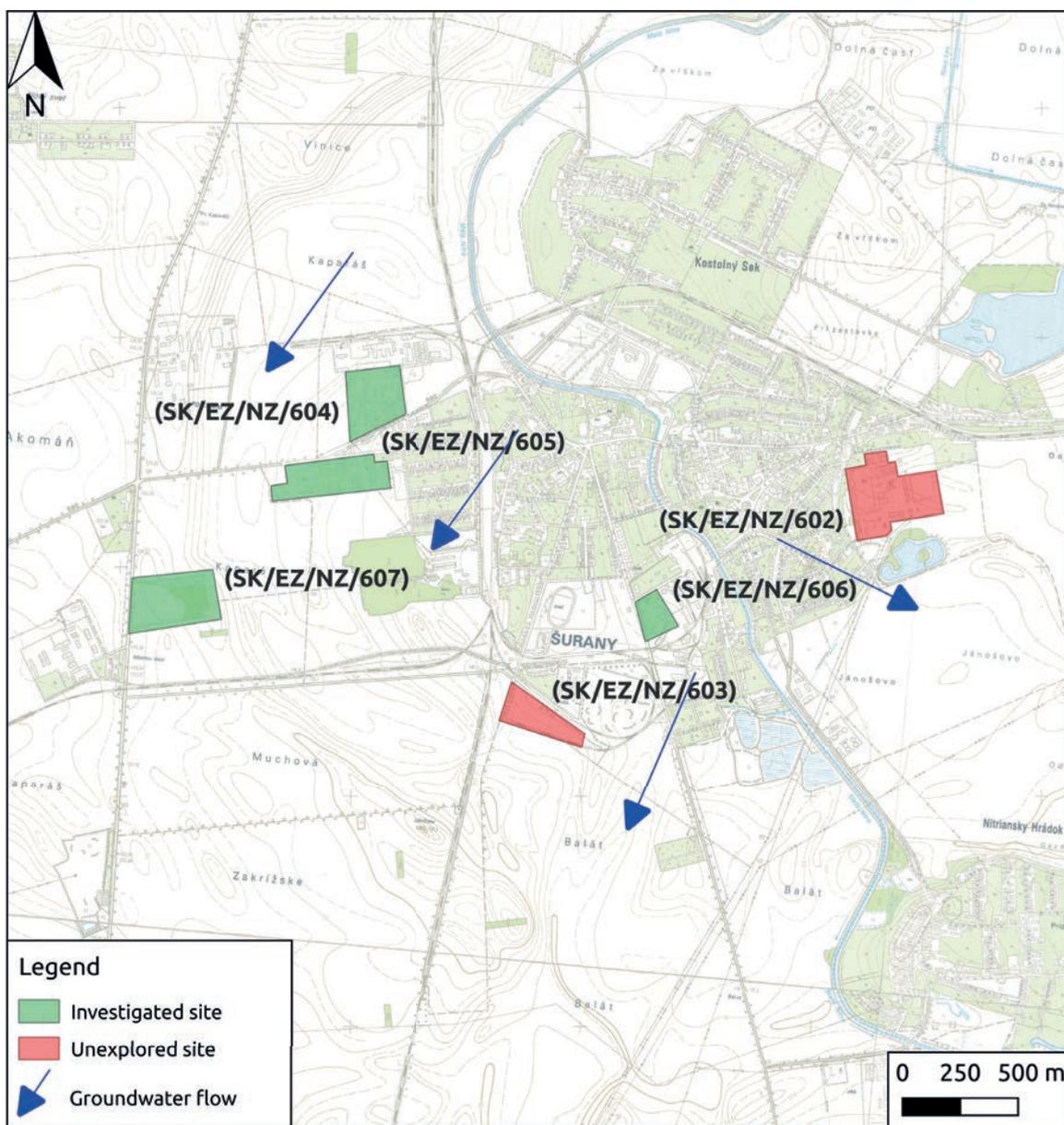


Fig. 1. Environmental burdens in Šurany municipality

transition to a market economy in 1989, former socialist companies had problems with sales and gradually ceased operations. Today, the former production facilities are used in a different way. The type of production activity, together with the approach to environmental protection at the time, meant that all of the above-mentioned plants were classified as probable environmental burdens (EB) when the environmental burden information system was created in 2010 (<https://envirozataze.enviroportal.sk/>). Through several projects implemented by the Ministry of the Environment of the Slovak Republic, probable burdens in the town of Šurany were selected for detailed geological environmental surveys. The first geological survey focused on environmental burdens was carried out in 2015. The results showed massive groundwater contamination by chlorinated aliphatic hydrocarbons in the EB area, as well as their spreading downgradient with groundwater flow (Tupý et al., 2015). Currently, there are 6 probable/verified EBs registered in the cadastre of the municipality of Šurany, none of which had been remediated by 2025.

In 2022, according to the Register of EBs, there were 6 sites registered in Šurany in registers A (probable environmental burden) and B (confirmed environmental burden). Their position in relation to the town of Šurany is shown in Figure 1. Four of them were the subject of a detailed geological survey and two were classified as probable environmental burdens without more detailed information on the state of pollution. Detailed geological surveys of the environment constituted an extensive set of works aimed at identifying and evaluating the presence of pollution in soil air, rock environment and groundwater. Given that a significant portion of the pollution (or pollution posing a risk to environmental components) was identified in groundwater, this study focuses on the assessment of this matrix. The authors of the study formed the core of the teams that conducted geological surveys at three sites in 2022 and 2023 – municipal solid waste dump [SK/EZ/NZ/607 (Tupý et al., 2022c)], former sugar mill [SK/EZ/NZ/606 (Tupý et al., 2022b)], former CALEX site [SK/EZ/NZ/604 (Tupý et al., 2022a)]. Due to problems with access to the site, part of the CALEX site was surveyed in 2022 (Tupý et al., 2022a) and the remaining part in 2023 (Macek et al., 2023). The fourth EB – the former ELITEX and STS site (SK/EZ/NZ/605) – was investigated in 2015. The site of the former CALEX plant, located upgradient of the ELITEX and STS EBs, was identified as a possible source of CAHs groundwater contamination (Tupý et al., 2015). The assumption of high concentrations of CAHs was based on an analogy with a similar site – the CALEX plant in Zlaté Moravce. In 2022, the remediation of the main CALEX plant in Zlaté Moravce was completed, where free phase of CAHs was present at the bottom of the aquifer (Auxt et al., 2022). From 2016 to 2023, the State Geological Institute of Dionýz Štúr monitored the quality of groundwater at the site (Kordík et al., 2023).

General geological characteristics of the north-east part of Danubian Lowland

In the north-eastern part of the Danube Lowland, the basement of the Neogene depression is formed by crystalline and Mesozoic rocks. The oldest Neogene formation is the Badenian, whose rocks were identified near Šurany (Lower Badenian). The Badenian marked a fundamental change in the development of the entire Danube Basin, which manifested itself in significant subsidence and volcanic activity. The territory is largely covered by Quaternary – Pleistocene and Holocene sediments (Priečovská et al., 1988). Quaternary sediments dominate the Nitra Hills. They continuously cover the southern, less the central and northern parts of the territory. The thickness of the cover increases from north to south and from the surrounding mountains to the central parts of the hills. Loess and loess-like sediments play a major role, while the second most significant type are fluvial sediments, which fill depressions and hollows. The thickness of Quaternary sediments rarely exceeds 25 m, with a maximum in the southern part on the terraces of the confluence of the Nitra and Váh rivers (Pristaš et al., 2000).

The town of Šurany lies on fluvial sediments linked to the valley of the Nitra River and its larger tributaries. In the flat area around Šurany, they form a continuous layer on a tectonically subsiding territory. At the base, there are gravels and sands belonging to the low terrace. Above them are Holocene clays (sandy to loamy). In the vicinity of Šurany, organic sediments consisting of dark to black clays with a significant proportion of organic matter have been preserved. Overall, the sediments are mostly grey and brownish-grey, with lighter or darker shades in places. A typical feature is the occurrence of carbonates. The total thickness of Holocene fluvial sands is 1–3 m, rarely up to 5 m (Priečovská et al., 1988; Pristaš et al., 2000).

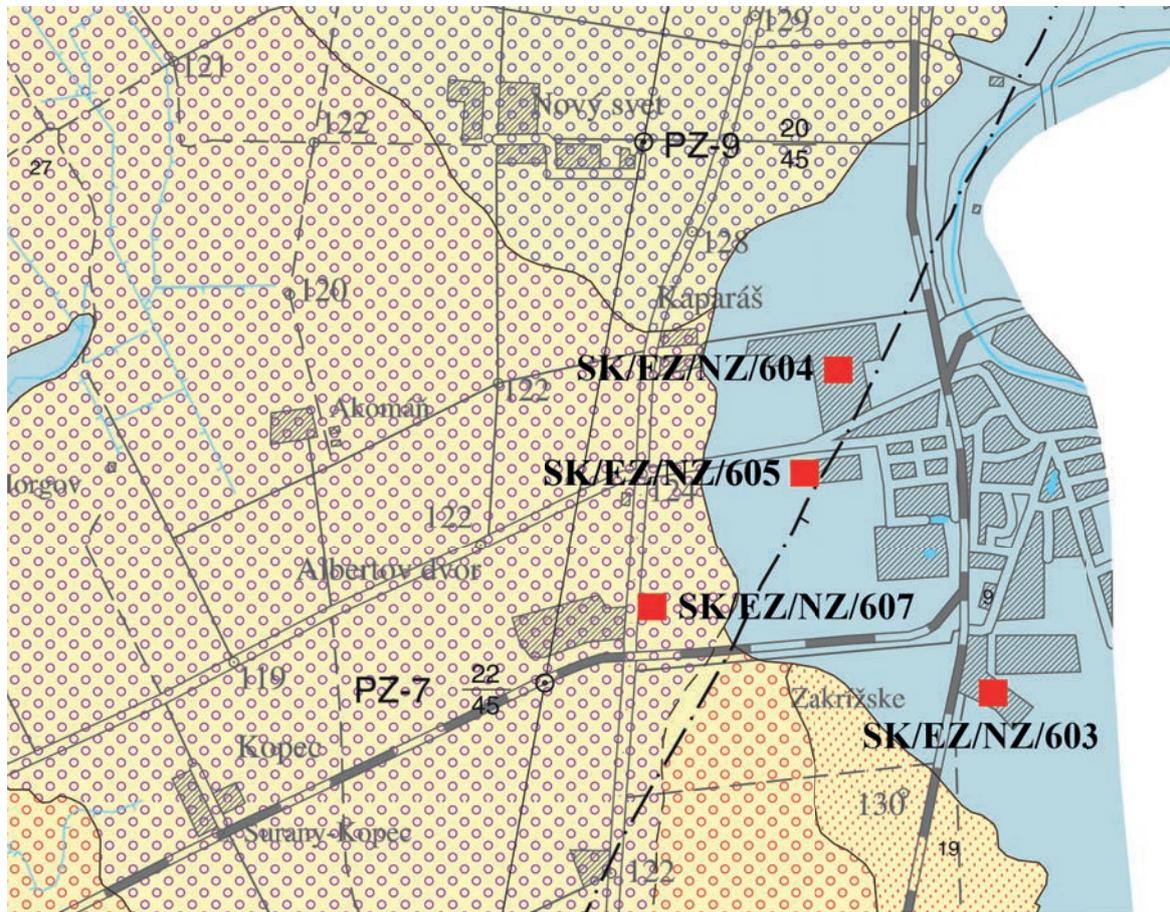
The area is located west and southwest of the town of Šurany (Fig. 2). West of the town, there are Pleistocene fluvial sediments (younger Riss) – sandy gravels of the lower terrace covered with loess and loess loams. The main lower terrace is one of the most widespread terrace levels in the region, protruding significantly mainly on the left bank of the Nitra River. Between Sered' and Nové Zámky, it borders the southwestern edge of the Nitra Hills – the Nitra Plateau – with a wide strip. The width of the terrace reaches 4–5 km in places, or even more. The surface of the terrace is located approximately 8–12 m above the floodplains of the rivers. The terrace is mostly covered by loess and loess loam. The upper layer of the terrace profile in the area west of Šurany contains humus black earth and brown earth soils of the Riss-Würm interglacial period (Pristaš et al., 2000). Southwest of the town, there are Pleistocene fluvial sediments (Würm) – sandy gravel and sand of a low terrace covered with washed-out loess

and marsh loess. The low terrace at a relative height of 4–6 m (maximum 8 m) above the floodplains has the lowest morphological position in the Nitra Valley between the terraces. The surface of the terrace near Šurany is slightly undulating with clear signs of deflation and eolian activity. In the area southwest of Šurany, light yellow to grey, in places brownish to greenish, dusty to fine-sandy calcareous clay – marsh loess – protrudes from the overburden of fluvial clays and sands (Pristaš et al., 2000).

Geological characteristics of the area

In the western part of Šurany, the geological conditions have been verified by several surveys in the past. Neogene

sediments have been identified beneath the Quaternary sediments, consisting of gravelly sandy layers with occurrences of sandy clays, but the Quaternary-Neogene boundary is unclear. The interface is reported at a level of 21 m below ground surface (Obuch, 2008). The thickness of the clay layers in the boreholes reached approximately 3 m (Kmeť, 2008). From approximately 3.0 m below ground surface, the first water-bearing horizon of sand or sandy gravel is located. A 55 m deep borehole detected alternating gravel and clay layers from approximately 9.0 m below ground surface (0.0–4.0 m clay; 4.0–9.0 m sand; 9.0–11.0 m gravel; 11.0–14.0 m gravel; 14.0–16.0 m clay; 16.0–23.0 m gravel; 23.0–27.0 m clay; 27.0–29.0 m



Legend:

	Holocene: loams, sandy loams, clays, loamy sands and gravels of river and creek flood plains
	Würm, eolian sediments: sands with short eolian transport

	Würm, fluvial sediments: sandy gravels and sands of lower terrace with cover of redeposited loesses and swamp loesses
	Upper Riss, fluvial sediments: sandy gravels of lower middle terrace with loesses and loess loam covers
	Lower Riss, fluvial sediments: sandy gravels of upper middle terrace with loesses cover and cover of run-off loesses

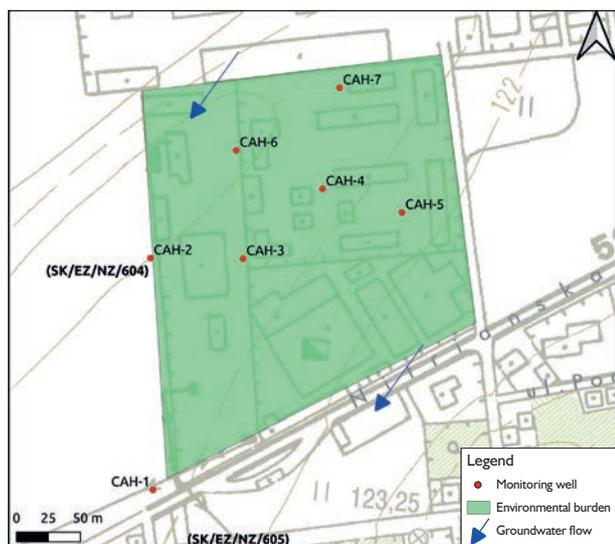
Fig. 2. Šurany area geological setting (Pristaš et al., 2000)

gravel; 29.0–36.0 m clay; 36.0–38.0 m sand; 38.0–44.0 m clay; 44.0–47.0 m gravel; 47.0–48.5 m sand; 48.5–51.0 m clay; 51.0–54.5 m gravel; 54.5–55.0 m clay), which are approximately 2.0 m thick (Obuch, 2008). A similar lithological development was also observed in a 65 m deep borehole drilled near the CALEX site (Kertész et al., 1978). The hydraulic conductivity values, calculated on the basis of pumping test results, were $K = 1.66 \cdot 10^{-4} \text{ m}\cdot\text{s}^{-1}$ (Kertész et al., 1978) and $K = 8.06 \cdot 10^{-4} \text{ m}\cdot\text{s}^{-1}$ (Obuch, 2008). The aquifer is represented by gravelly sand formation and the groundwater flow is characterized by intergranular permeability. The water-saturated bed of poorly graded sand (from approx. 3.5 m below ground level) is highly

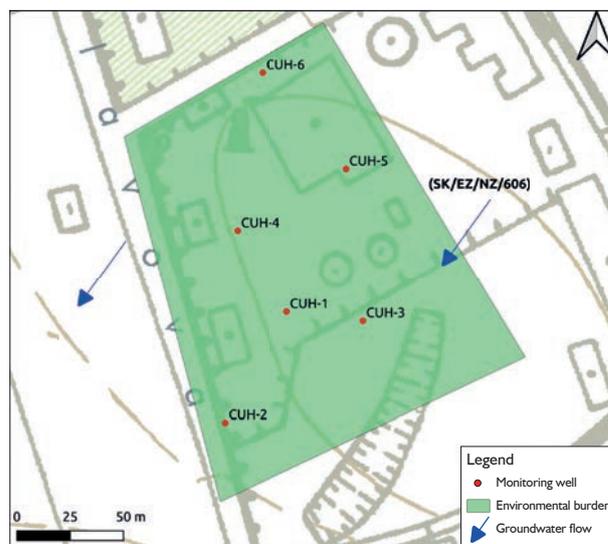
permeable. The general direction of groundwater flow is on the right side of the Malá Nitra River NE–SW, on the left side NW–SE, and the groundwater is confined.

Material and methods

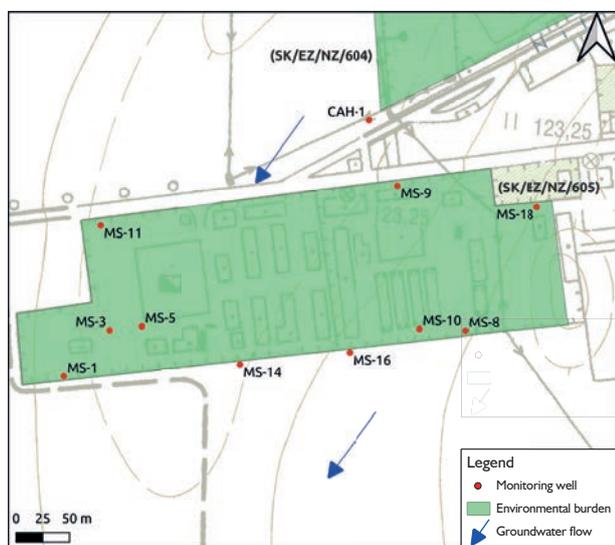
Geological surveys were carried out using a uniform methodology in accordance with the Methodological Guide for Geological Surveys of the Environment in Contaminated Areas (Schwarz et al., 2020). After the drilling of new wells, groundwater samples were collected after short pumping. The sampling was combined with measurements of the groundwater level. Field parameters [temperature, oxidation-reduction potential (ORP), pH,



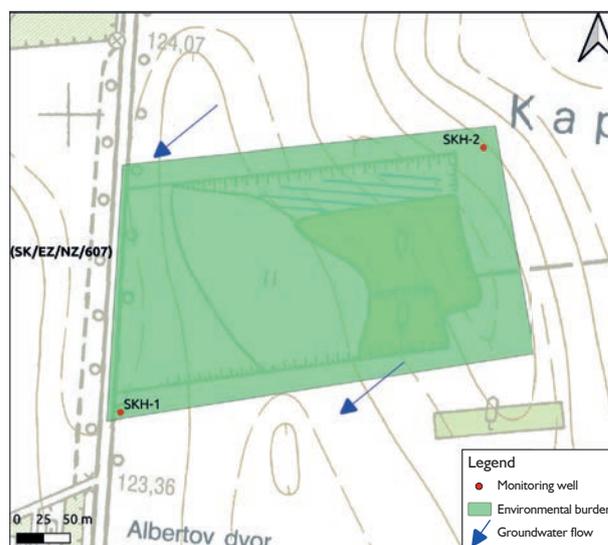
Former CALEX plant (SK/EZ/NZ/604)



Former sugar mill (SK/EZ/NZ/606)



Former ELITEX and STS plants (SK/EZ/NZ/605)



Municipal solid waste dump (SK/EZ/NZ/607)

Fig. 3. Depiction of the investigated sites

electrolytic conductivity (EC), dissolved oxygen (DO)] were measured prior to sampling. The measurements were performed with a calibrated Hanna HI98194 multimeter in a flow-through vessel. Groundwater samples were collected using a 12 V Gigant submersible pump (flow rate 0.1 L.s⁻¹). After rinsing the sample container (EPA VIAL) with groundwater, it was then filled so that no water bubbled over and no air was present in the filled sample container. Due to the priority pollutants (CAHs), groundwater samples were taken from the lower part of the water column (at the bottom of the performed interval). The filled sample containers were placed in cooled transport bag and immediately transported to an accredited laboratory.

Analytical work was carried out in an accredited laboratory in accordance with internal operating procedures – determination of volatile organic compounds (vinyl chloride, trans-1,2-dichloroethene, cis-1,2-dichloroethene; trichloroethene, tetrachloroethene) using gas chromatography with FID and MS detection and calculation of the sum of volatile organic compounds from the measured values. The analytical methods used corresponded to US EPA 624, US EPA 5021A, US EPA 8260, US EPA 8015. The obtained values were graphically processed by kriging interpolation in Golden Software Surfer 16.0.

The situation of the evaluated environmental burdens within the town of Šurany is shown in Figure 1, and the detailed location of the sampled wells at individual sites is shown in Figure 3.

Results and discussion

The assessment of groundwater contamination in the area of Šurany was carried out on the basis of the results of surveys conducted in 2022 and 2023, together with the results of monitoring of the ELITEX and STS sites. The content of pollutants in groundwater was assessed in accordance with Directive of the Ministry of the Environment of the Slovak Republic No. 1/2015-7 on the preparation of a risk analysis of contaminated sites (hereinafter referred to as the “Directive”). The results of the first geological survey identified significant contamination of groundwater with CAHs (Tab. 1). The area of contamination, obtained by data interpolation, was in the case of PCE more than 10 hectares (concentrations higher than the Directive indicative criterion value for individual parameters) and more than 7 hectares (concentrations higher than the Directive intervention criterion value). An indicative criterion (ID) is a threshold value for the concentration of a pollutant, the exceeding of which may endanger human health and the environment. An intervention criterion (IT) is a critical value for the concentration of a pollutant, the exceeding of which is likely to endanger human health and the environment.

Tab. 1

Maximum concentrations of selected contaminants in 2015, ELITEX and STS (according to Tupý et al., 2015), *IT Criterion from the Directive of Ministry of Environment of the Slovak Republic No. 1/2015-7

Parameter (Well)	Maximum identified concentration [µg.L ⁻¹]	IT Criterion value* [µg.L ⁻¹]
VC (VS-4)	118	10
DCE (VS-4)	2,720	50
TCE (MS-4)	7,010	50
PCE (MS-1)	467	20

Table 2 shows the results of field parameters measured prior to groundwater sampling. The measurements taken in autumn represent more extensive data sets; measurements at the CALEX site in 2023 were taken during two sampling cycles (March 2023, May 2023). From the municipal solid waste dump (MSWD) site, only the part of the data that represents the properties of the water-saturated gravel layer was selected (there is also a second water-saturated level at the site, located in the body of the landfill).

When evaluating the results of field measurements in the western part of the city, it is clear that the measured values do not differ significantly among individual sites. The median temperatures ranged from 13.5 °C (MSWD) to 14.3 °C (CALEX). The higher water temperature in the CALEX area in 2023 is the result of a change in the season in which the measurements were taken. The deviations from the maximum and minimum values were small. Overall, the measured values roughly correspond to the natural groundwater values at the site and the given season.

Similarly, no significant differences were identified in the measured pH values. The medians of the measured values at the individual sites ranged from 7.11 and 7.33 (CALEX) to 7.31 (MSWD). The deviations from the maximum and minimum values were small. These are natural values for groundwater, which do not show any significant anomalies with regard to the expected presence of pollutants.

The medians of the measured values of specific electrolytic conductivity ranged from 603 µS.cm⁻¹ (CALEX) to 806 µS.cm⁻¹ (sugar mill). The values are approximately at the same level. However, the differences between the sites in relation to the measured minimum and maximum values are more significant. Locally high values document anthropogenic influence on groundwater quality. This was most evident at the sugar mill site, where a value of up to 3,876 µS.cm⁻¹ (CUH-3) was measured. Differences were observed between the values within the site in wells

Tab. 2

Results of field measurements at investigated sites

Parameter	t [°C]	EC [$\mu\text{S.cm}^{-1}$]	DO [mg.L^{-1}]	pH	ORP [mV]
<i>CALEX – 131 measurements, October–November 2022</i>					
Minimum	12.1	309	0	6.42	–551
Maximum	16.2	876	6.12	7.89	303
Average	14.1	596	1.70	7.14	57
Median	14.3	603	0.98	7.11	137
<i>Sugar mill – 72 measurements, October–November 2022</i>					
Minimum	13.3	236	0.05	6.79	–241
Maximum	15.4	3,876	5.1	7.76	559
Average	14.0	1,314	2.31	7.21	190
Median	14.1	806	2.55	7.15	230
<i>MSWD – 73 measurements, October–November 2022</i>					
Minimum	11.5	455	0.29	6.99	–247
Maximum	15.6	1,002	4.78	7.56	580
Average	13.7	759	2.58	7.28	149
Median	13.5	744	2.96	7.32	83
<i>CALEX – 11 measurements, March – May 2023</i>					
Minimum	13.2	575	3.60	7.07	151
Maximum	16.8	1,040	5.20	7.44	208
Average	14.8	817	4.26	7.30	189
Median	14.8	759	4.20	7.33	193

CUH-1 to CUH-3, which are located in the direction of groundwater flow from the presumed source of pollution (fuel oil tanks), and wells in the area against the direction of groundwater flow (CUH-4 to CUH-6). In the former, conductivity values typically ranged around 2,000 $\mu\text{S.cm}^{-1}$, while in the case of well CUH-3, very high values exceeding the IT criterion of the Directive were measured (3,000 $\mu\text{S.cm}^{-1}$). In wells CUH-4 to CUH-6, the conductivity values measured were significantly lower (but probably also anthropogenically influenced), ranging from approximately 500 to 1,000 $\mu\text{S.cm}^{-1}$. Their occurrence mainly in the part where various secondary raw materials (mainly scrap metal) are temporarily stored indicates that they are more likely to be the result of activities carried out at the site at present (secondary raw material collection) than in the past (heavy fuel oil boiler). The median values obtained from measurements at the other two sites do not differ significantly from the values typical for natural conditions. According to Rapant et al. (1996), the median electrolytic conductivity for Quaternary groundwater (flu-

vial sediments of river plains) is 661 $\mu\text{S.cm}^{-1}$. Common groundwater and surface water conductivity values are 50 to 500 $\mu\text{S.cm}^{-1}$ (Pitter, 2015).

The measured values of DO in groundwater varied widely. At the CALEX site (in 2022), the minimum measured value was 0.0 mg.L^{-1} and the maximum value was 6.12 mg.L^{-1} . It is not possible to draw clear conclusions from the measured values that would link changes in DO concentrations to other phenomena [low DO concentrations may indicate increased CAHs concentrations (Oldenhuis et al., 1989)]. Significant differences in the measured values were also observed within a single well – wells marked CAH-XY at the CALEX site were sampled from three depth levels. For example, in the CAH-7 well, which serves as a background well at the site, both low (0.2 mg.L^{-1}) and relatively high concentrations (4.78 mg.L^{-1}) were measured. The results of measurements at the MSWD and sugar mill sites were similar.

Similar to DO, ORP values also showed a wide range. During the 2022 surveys, values at all three sites ranged

from negative (up to -551 mV, CALEX, indicating the presence of CAHs) to positive (up to 580 mV, MSWD). The medians of the measured ORP values ranged from 83 mV (MSWD) to 230 mV (sugar mill). Measurements in 2023 at the CALEX site form a balanced set of values ranging from 151 to 208 mV. Negative ORP values indicate a reducing environment (ability to transfer electrons). This may be due to limited oxygen access or the decomposition of organic matter by microorganisms. Positive ORP values indicate an oxidative environment (ability to accept electrons). Dissolved oxygen is present in the environment and oxidative reactions are energetically favorable.

Identifying the presence of pollutants is problematic based on the results of measurements of basic groundwater field parameters. At the sugar mill site, the lowest ORP values were measured in well CAH-5, which is located outside the presumed source of pollution. In the other observed wells, located in the direction of groundwater flow from the presumed source of contamination (CUH-1, CUH-2, CUH-3, CUH-4), as well as in the background well CUH-6, the measured ORP values were predominantly positive or ranged between oxidative and reductive conditions (value of 200 mV). The situation at the CALEX site was comparable. The CAH-1 well, in which the highest degree of CAHs contamination was identified, had predominantly positive ORP values, or values ranging between oxidative and reductive conditions (200 mV). Negative or low ORP values were observed

in water from wells CAH-6 and CAH-7, which serve as background wells at the site. However, it is possible that there are other factors affecting groundwater quality at the sites under investigation that could not be identified based on the input data.

The work carried out also included measurements of groundwater levels. For the purposes of graphical interpretation of the data, the results from 22nd November 2022 were used. Hydraulic contour lines created on the basis of the data obtained confirmed the general direction of groundwater flow on the right bank of the Malá Nitra stream, which was in the NE-SW direction (Fig. 4).

The direction of groundwater flow affects the spread of pollution further into the area. The source of CAHs is apparently the ELITEX and STS site. From there, the pollution spreads in a SW direction, reaching another EB (MSWD). High-permeability soils (gravels, sands) can comprise heterogeneous and homogeneous layers (Gill et al., 2014; Hansen et al., 2015). The grain sizes in such environments are large, which contributes to higher hydraulic conductivity $> 10^{-4}$ m.s $^{-1}$ and further pollution spreading (Appelo & Postma, 2005; Hyldegaard & Ottosen, 2021).

In 2015, high concentrations of CAHs were also identified in domestic wells in the Albertov dvor area, located approximately 80 m southwest of the MSWD (Tupý et al., 2015). Based on the results from 2022, a graphical interpretation of the spread of contamination from the source

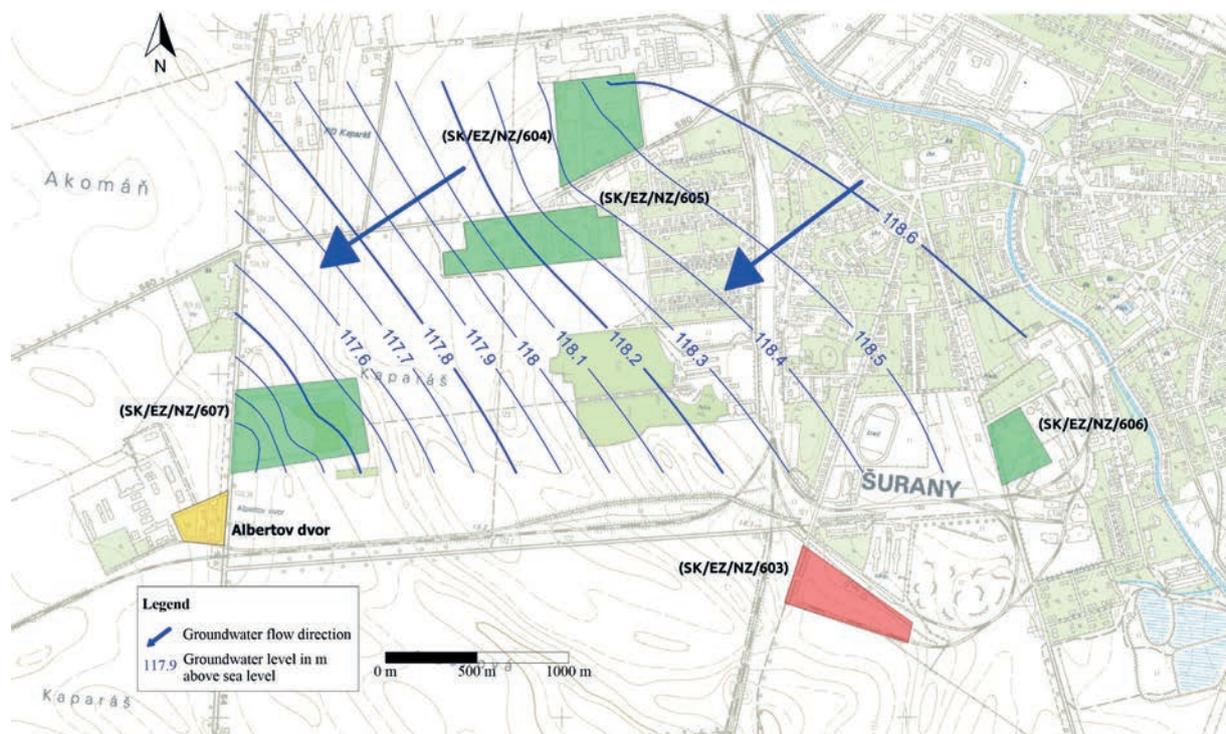


Fig. 4. Groundwater flow direction as of 22 November 2022

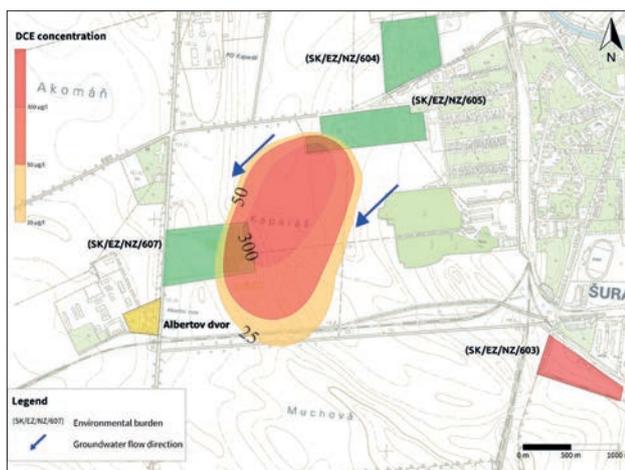
was prepared (Fig. 5). The contamination plume extends to the landfill, where CAHs concentrations in 14 samples from the SKH-2 well ranged from 291 to 469 $\mu\text{g.L}^{-1}$ (DCE), from 574 to 842 $\mu\text{g.L}^{-1}$ (TCE) and from 63.6 to 125 $\mu\text{g.L}^{-1}$ (PCE). In samples from the MS-1 well, located at the source of pollution (ELITEX and STS), the concentrations in the 8 samples were significantly higher. They

ranged from 952 to 2,810 $\mu\text{g.L}^{-1}$ (DCE), 701–2,970 $\mu\text{g.L}^{-1}$ (TCE), 69.5–194 $\mu\text{g.L}^{-1}$ (PCE), and unlike well SKH-2, VC concentrations were also high (37–168 $\mu\text{g.L}^{-1}$). The following table shows the concentration ranges of individual pollutants detected in groundwater samples (Tab. 3).

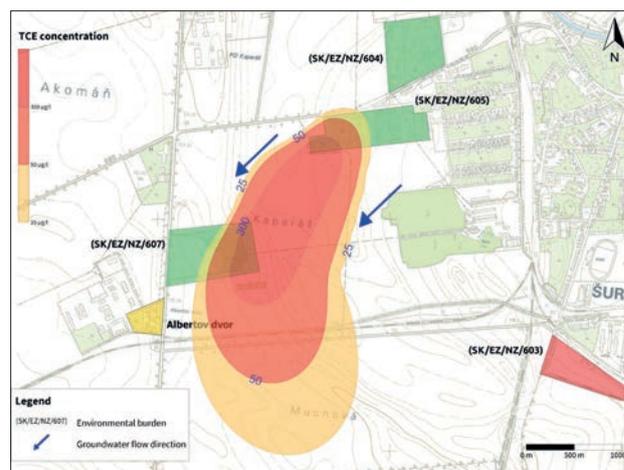
The following figures (Fig. 6, Fig. 7) show the interpreted development of DCE, TCE and PCE concentrations

Tab. 3
Contaminant concentrations in selected wells

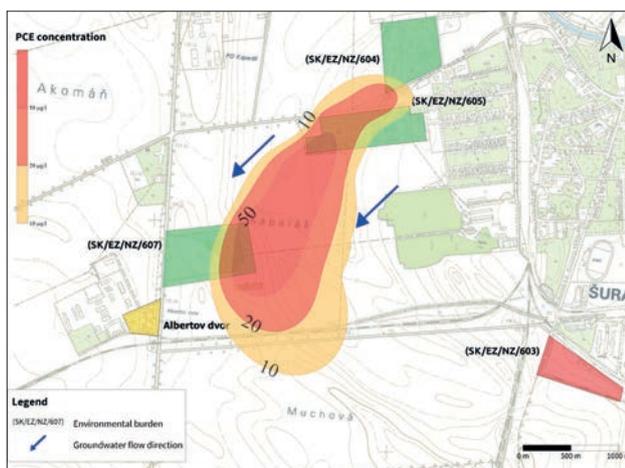
Well	Year of sampling	Number of samples	DCE [$\mu\text{g.L}^{-1}$]	TCE [$\mu\text{g.L}^{-1}$]	PCE [$\mu\text{g.L}^{-1}$]	VC [$\mu\text{g.L}^{-1}$]	Site
MS-1	2022	8	952–2,810	701–2,970	69.5–194	37–168	SK/EZ/NZ/605
SKH-2	2022	14	291–469	574–842	63.6–125	< 1.00	SK/EZ/NZ/607
MS-3	2022	2	8.8–9.9	161–176	222–247	< 1.00	SK/EZ/NZ/605
CAH-1	2022	18	2.52–4.89	4.42–21.3	24.1–60.4	< 1.00	SK/EZ/NZ/604
CAH-1	2023	2	2.83–4.25	3.3–4.4	29–42	< 1.00	SK/EZ/NZ/604



DCE plume



TCE plume



PCE plume

Fig. 5. Interpolated contaminant plumes for DCE, TCE and PCE

in samples from well MS-1, together with the development of the groundwater level. The data presented are a synthesis of monitoring and survey results. The concentrations of pollutants are clearly dependent on changes in the groundwater level. When the level rises, pollutant concentrations usually decrease, and vice versa. However, the changes are

not a regular seasonal phenomenon, as the maximum and minimum groundwater levels in the monitored period do not correspond to seasonal changes.

More accurate identification of the source of pollution at the ELITEX site is possible thanks to data from 2015 (Tupý et al., 2015) and monitoring results from 2016 to

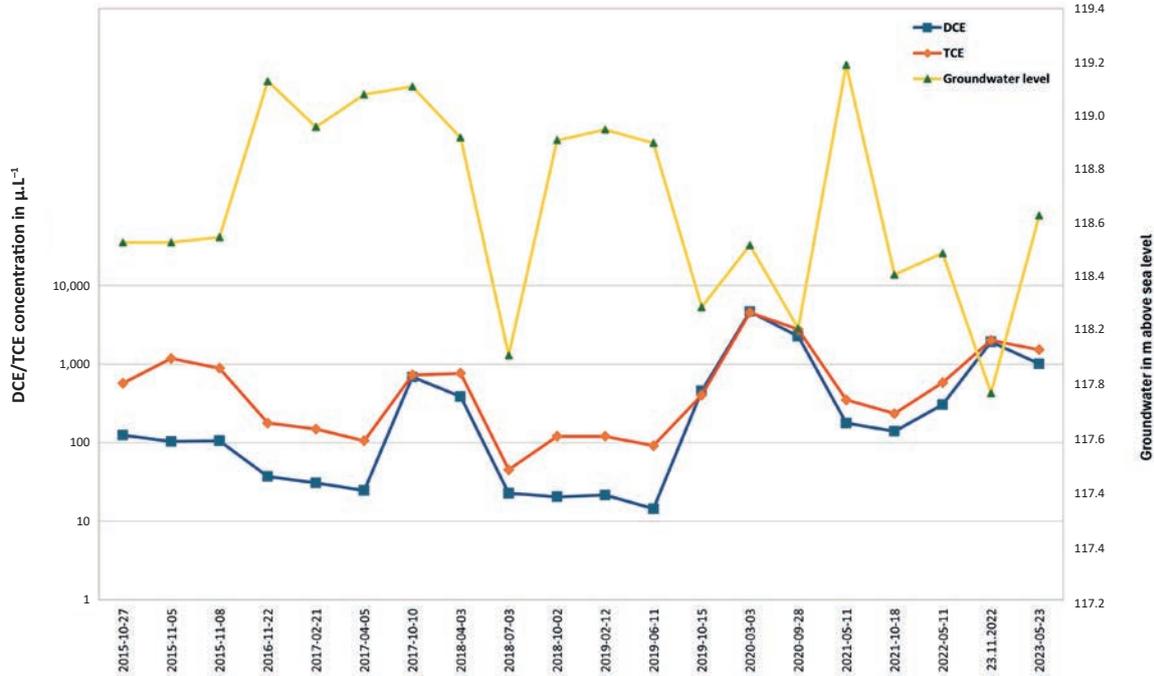


Fig. 6. DCE and TCE concentration change in well MS-1 in relation to groundwater level

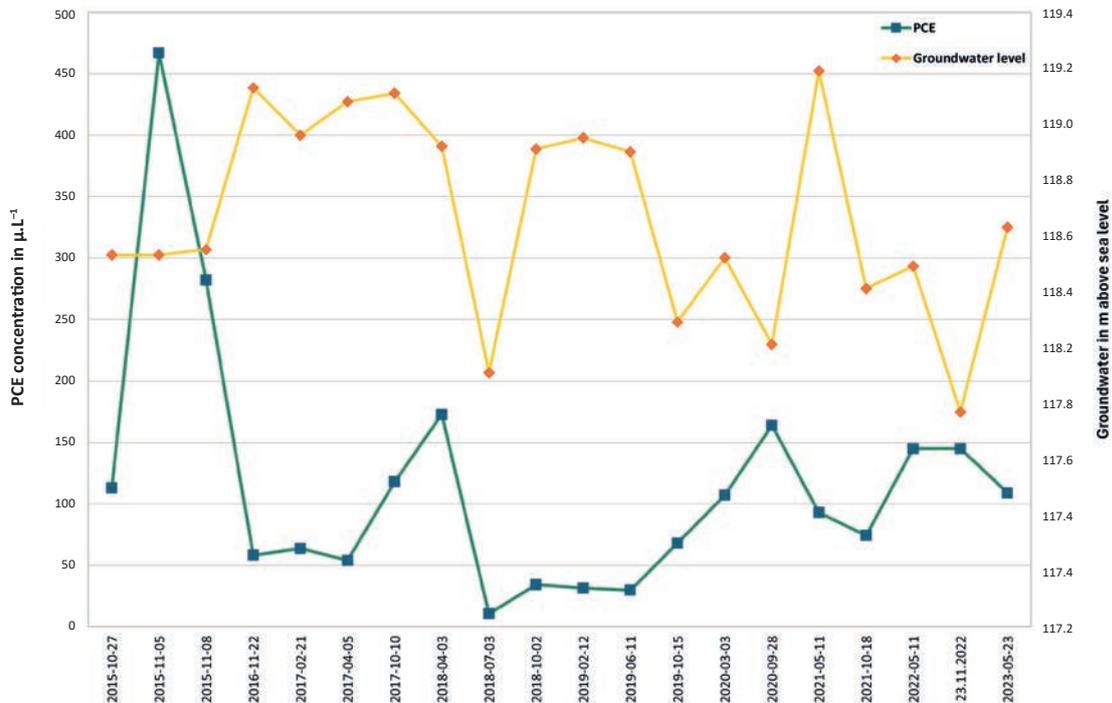


Fig. 7. PCE concentration change in well MS-1 in relation to groundwater level

2023 (Kordík et al., 2023). In terms of CAHs concentrations, the monitored wells can be classified into several groups, or, on this basis, sub-areas with varying degrees of contamination can be identified. The MS-1, MS-3 and MS-5 wells, located in the south-western part of the ELITEX site, define the area with the most significant source of contamination. In wells MS-8, MS-10, MS-14 and MS-18, high concentrations of some of the monitored pollutants were identified only in the 2015 sample. In the last three monitored wells, the presence of pollution was rarely recorded, with a time lag (MS-9 in 2015, 2022, MS-11 in 2015, 2017, 2022, MS-16 in 2015, 2022). Wells with low or occasionally high concentrations are located mainly around the perimeter of the EB, so it is possible to more accurately define the source within the site.

The results of the 2023 survey in the CALEX site (Macek et al., 2023) clearly show that the source of contamination (PCE) detected during the 2022 survey (Tupý et al., 2022a) is not located on the site of the former CALEX plant. Low concentrations of CAHs (DCE, TCE, PCE) were identified by both surveys throughout the CALEX site, but only in low concentrations (with the exception of the vicinity of the CAH-5 well, where PCE concentrations exceeded the ID criterion value of the Directive). Given the degree of contamination at the ELITEX site and the characteristics of the geological environment [alternating layers of sandy gravel and sandy clay (Obuch, 2008; Pristaš et al., 2000)], it can be assumed that the contamination in the CAH-1 well is the result of gravitational transport of CAHs through an impermeable layer towards the CALEX site (the well is located approximately 60 m from the ELITEX site). DNAPLs migrating below the water level move downward and laterally under the influence of gravity, capillary, and viscous forces (Conrad & Glass, 2000), and under certain conditions, gravitational forces may prevail over hydraulic forces (Dawson & Roberts, 1997).

The continuous spread of pollution from the ELITEX and STS sites to a large area in the town of Šurany requires remediation. Theoretical background and practical experience from other sites in Slovakia suggest that a suitable solution is to create a reactive barrier, which essentially involves creating reducing conditions by applying aqueous reagents to the contaminated environment (e.g., whey, sulfidized zero-valent iron, etc.). In the process of reductive dechlorination by the action of reagents, reduced forms of the contaminant with less harmful or less dangerous properties are formed in groundwater (transition of PCE to DCE). Remediation can be carried out passively (without the need to pump groundwater). The main source of pollution is well defined, and the technical facilities (wells) needed to create a barrier could be located at the interface between the former ELITEX site and agricultural land (subject to agreement with the landowners). After

pilot tests aimed at selecting the most effective agent, the main challenge would remain the sustainability of the project – continuous monitoring of effectiveness and possible changes in the technological processes of groundwater remediation. However, the intensity of the spread of pollution, as well as its volume, pose a significant risk to groundwater quality over a large area. Addressing this situation should be one of the city's priorities.

Conclusions

Based on the results of the surveys and monitoring carried out, it was confirmed that there is widespread contamination with chlorinated aliphatic hydrocarbons in a relatively large area in the western part of the town of Šurany (ca 80 hectares). The secondary source of contamination (CAHs in the rock environment) is still active, meaning that the contamination plume is still growing. A comprehensive assessment of geological tasks carried out in 2022 and 2023, together with the results of ELITEX and STS site monitoring, have enabled a more accurate definition of the source of pollution, as well as modelling of the likely direction and intensity of pollution spread in the direction of groundwater flow.

The identified state of groundwater pollution clearly requires remediation work. Currently, it is possible to choose suitable procedures that have been field-tested with good results. Traditional methods include, for example, pump and clean treatment, using chemical oxidation/reduction and reactive permeable barriers, electrochemical methods as well as bioremediation. To achieve the optimal effect of remediation work, it is recommended to carry out laboratory experiments that simulate the properties of the geological environment and pollutants as accurately as possible.

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Environmentálne záťaže v Šuranoch – znečistenie podzemnej vody chlórovanými alifatickými uhl'ovodíkmi

Cieľom štúdie je hodnotenie šírenia znečistenia z viacerých možných zdrojov, ktoré sa nachádzajú neďaleko od seba v západnej časti intravilánu mesta Šurany. Mesto Šurany leží v Podunajskej nížine, v južnej časti Slovenska. V minulosti bola v meste koncentrovaná priemyselná a potravinárska výroba, ktorá zamestnávala ľudí zo širšieho okolia mesta (výrobné podniky CALEX, ELITEX, STS, cukrovar). Napriek skončeniu aktivity v uvedených prevádzkach pred viac ako 30 rokmi znečistenie podzemnej vody pretrváva vo vysokej koncentrácii. Druh výrobnej činnosti spolu s vtedajším prístupom k ochrane životného prostredia zapríčinili, že všetky uvedené prevádzky boli pri vzniku registra environmentálnych záťaží zaradené ako pravdepodobné environmentálne záťaže. V roku 2022 bolo v Šuranoch podľa uvedeného registra evidovaných 6 lokalít. Štyri z nich boli predmetom podrobného geologického prieskumu [mestská skládka tuhého komunálneho odpadu (SK/EZ/NZ/607); bývalý cukrovar (SK/EZ/NZ/606); bývalý areál CALEX (SK/EZ/NZ/604); bývalý areál ELITEXU a STS (SK/EZ/NZ/605)] a dve ako pravdepodobné environmentálne záťaže bez podrobnejších informácií

o stave znečistenia [areál bývalého ELITEXU, Družstevná 5 (SK/EZ/NZ/602); Šurany – areál Kovošrotu (SK/EZ/NZ/603)].

Mesto Šurany leží na fluviálnych sedimentoch viazaných na dolinu toku Nitry a jej väčších prítokov. V rovinnom stupni v okolí Šurian tvoria súvislú vrstvu na tektonicky poklesávajúcom území. Na báze sú štrky až piesky patriace k nízkej terase. V ich nadloží sa nachádzajú holocénne hliny (piesčité až ílové). V západnej časti Šurian boli geologické podmienky v minulosti overené viacerými prieskumami. Pod kvartérnymi uloženinami boli identifikované neogénne sedimenty tvorené štrkopieskovými telesami s výskytom piesčitých ílov, hranica kvartér/neogén je však nejasná. Obuch (2008) uvádza rozhranie na úrovni 21 m p. t. Ílovité vrstvy vo vrtoch dosahovali hrúbku zhruba 3 m (Kmeť, 2008). Približne od 3,0 m p. t. je prvý zvodnený horizont pieskov, resp. piesčitých štrkov. Vrt hlboký 55 m p. t. zhruba od 9,0 m p. t. zachytil striedanie štrkových a ílových vrstiev, ktoré sú hrubé približne 2,0 m (Obuch, 2008). Hodnoty koeficientu filtrácie, vypočítané na základe výsledkov čer-

pacích skúšok, boli $k_f = 1,66 \cdot 10^{-4} \text{ m} \cdot \text{s}^{-1}$ (Kertesz, 1978), resp. $k_f = 8,06 \cdot 10^{-4} \text{ m} \cdot \text{s}^{-1}$ (Obuch, 2008). Generálny smer prúdenia podzemnej vody na pravej strane toku Malá Nitra je SV – JZ, na ľavej strane SZ – JV, hladina podzemnej vody je napätá.

Hodnotenie znečistenia podzemnej vody v priestore mesta Šurany sa urobilo na základe výsledkov prieskumov vykonaných v rokoch 2022 a 2023 spolu s výsledkami monitorovania lokality ELITEX a STS. V roku 2015 boli CIU vo vysokej koncentrácii identifikované aj v domových studniach v časti Albertov dvor, ktorá sa nachádza vo vzdialenosti asi 80 m jz. smerom od EZ mestská skládka (Tupý et al., 2015). Na základe výsledkov z roku 2022 sme spracovali grafickú interpretáciu šírenia znečistenia od zdroja. Mrak znečistenia siaha až po EZ mestská skládka, kde sa koncentrácia CIU v 14 vzorkách z vrtu SKH-2 pohybovala v rozsahu $291 - 469 \mu\text{g} \cdot \text{l}^{-1}$ (DCE), $574 - 842 \mu\text{g} \cdot \text{l}^{-1}$ (TCE) a $63,6 - 125 \mu\text{g} \cdot \text{l}^{-1}$ (PCE). Vo vzorkách z vrtu MS-1, ktorý sa nachádza v zdroji znečistenia, bola koncentrácia v 8 odobratých vzorkách výrazne vyššia. Pohybovala sa v rozsahu $952 - 2\,810 \mu\text{g} \cdot \text{l}^{-1}$ (DCE), $701 - 2\,970 \mu\text{g} \cdot \text{l}^{-1}$ (TCE) a $69,5 - 194 \mu\text{g} \cdot \text{l}^{-1}$ (PCE). Na rozdiel od vrtu SKH-2 bola vysoká aj koncentrácia VC ($37 - 168 \mu\text{g} \cdot \text{l}^{-1}$).

Presnejšiu identifikáciu zdroja znečistenia v areáli ELITEX umožňujú údaje z roku 2015 (Tupý et al., 2015) a výsledky monitorovania z rokov 2016 – 2023 (ŠGÚDŠ). Vrty MS-1, MS-3 a MS-5, ktoré sú situované v jz. časti areálu ELITEX, vymedzujú územie s najvýraznejším zdrojom znečistenia. Z výsledkov prieskumu v EZ CALEX v roku 2023 (Macek et al., 2023) je zrejme, že zdroj znečistenia (PCE), ktoré bolo zachytené počas prieskumu v roku 2022 (Tupý et al., 2022a), sa nenachádza v priestore

bývalého podniku CALEX. CIU migrujúce pod hladinou podzemnej vody vplyvom gravitácie, kapilárnych a viskózných síl sa pohybujú smerom nadol a do strán, pričom za istých podmienok môže gravitačné pôsobenie prevažovať nad hydraulickým.

Na základe výsledkov realizovaných prieskumov a monitorovania môžeme konštatovať, že v západnej časti mesta Šurany je plošné znečistenie chlórovanými alifatickými uhľovodíkmi na pomerne rozsiahlej ploche (zhruba 80 hektárov). Sekundárny zdroj znečistenia (CIU v horninovom prostredí) je stále aktívny, čiže mrak znečistenia sa stále zväčšuje. Komplexné hodnotenie geologických úloh realizovaných v rokoch 2022 a 2023 spolu s výsledkami monitorovania EZ ELITEX umožnilo presnejšie vymedzenie zdroja znečistenia, ako aj modelovanie pravdepodobného smeru a intenzity šírenia znečistenia v smere prúdenia podzemnej vody. Identifikovaný stav znečistenia podzemnej vody jednoznačne vyžaduje sanačné práce. V súčasnosti je možné zvoliť vhodné postupy, ktoré boli s dobrými výsledkami overené v praxi. Tradičnými metódami sú napríklad čerpanie a čistenie podzemnej vody, využitie chemickej oxidácie/redukcie a reaktívnych priepustných bariér, elektrochemické metódy a bioremediácia. Na dosiahnutie optimálneho efektu sanačných prác sa odporúča realizovať laboratórne experimenty, pri ktorých sa čo najvernejšie simulujú vlastnosti geologického prostredia a znečisťujúcich látok.

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