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Recognition of the efficiency of the structure of an active municipal waste landfill based on the quality of the water environment

Abstract

A landfill site is an engineered facility intended for depositing waste. Regardless of their type, such facilities pose a potential threat to the water and ground environment, as well as to human health and life, because leachate water in contact with groundwater deteriorates their quality. To prevent such a phenomenon, it is necessary to periodically test the composition of water within the landfill. The aim of the research was to analyse the efficiency of the structure of an operated municipal waste landfill based on the analysis of the composition of leachate and groundwater, including the operation and post-operation phases. Based on the physico-chemical analysis of leachate and groundwater in 2016-2020, increased average TOC (Total Organic Carbon) values exceeding 10 $mg \cdot dm^{-3}$ were shown. Although the concentrations of other indicators, including heavy metals, were within permissible limits, the test results showed limited efficiency of the barrier protecting against the impact of stored waste on the aquatic environment. For this reason, there was a need to expand the scope of research, in particular to include toxicity tests of both leachates and water.

Keywords: waste, sealing, monitoring, groundwater, leachate.

Rozpoznanie sprawności konstrukcji czynnego składowiska odpadów komunalnych na podstawie jakości środowiska wodnego

Streszczenie

Składowisko odpadów jest urządzonym obiektem inżynieryjnym przeznaczonym do deponowania odpadów. Niezależnie od ich rodzaju, obiekty takie stwarzają potencjalne zagrożenie dla środowiska wodno-gruntowego, a także dla zdrowia i życia ludzi, gdyż wody odciekowe w kontakcie z wodami podziemnymi wpływają na pogorszenie ich jakości. Aby zapobiec takiemu zjawisku konieczne jest okresowe przeprowadzanie badań składu wód występujących w obrębie składowiska. Celem badań była analiza sprawności konstrukcji eksploatowanego składowiska odpadów komunalnych na podstawie analizy składu wód odciekowych i podziemnych, obejmującej fazę eksploatacji i poeksploatacyjną. Na podstawie analizy fizyczno-chemicznej wód odciekowych i podziemnych w latach 2016-2020 wykazano podwyższone średnie wartości OWO (Ogólny Węgiel Organiczny) przekraczające 10 $mg \cdot dm^{-3}$. Pomimo, iż stężenia pozostałych wskaźników, w tym metali ciężkich mieściły się w granicach dopuszczalnych, wyniki badań wykazały ograniczoną sprawność przesłony chroniącej przed oddziaływaniem składowanych odpadów na środowisko wodne. Z tego względu wskazano na potrzebę poszerzenia zakresu badań w szczególności o testy toksyczności zarówno odcieków, jak i wód.

Słowa kluczowe: odpady, uszczelnienie, monitoring, wody podziemne, wody odciekowe.

1. Introduction

There are surface and underground waters within the landfill site, which, in contact with leachate water, pose a potential threat to human health and life, as well as the natural environment due to the potential ease of migration of pollutants. Surface waters are mainly fed by atmospheric precipitation and are reservoirs, rivers or lakes, as well as transitional and coastal waters. In turn, groundwater is supplied indirectly through the seepage of groundwater and rainwater. This is related to the conditions of rainwater infiltration (Bujakowski et al., 2014; Przydatek, 2012).

In accordance with the guidelines of the Regulation (2013), monitoring of landfills includes research in three phases, i.e. pre-exploitation, operational, and post-exploitation. During the first phase, the input condition is analysed and lasts until a building permit is issued, and during the second phase, it lasts from the moment of obtaining approval for development until consent is granted to close the landfill. However, the last one took into account 30 years since the closure of the facility (Mizerna, Bożem, 2015).

Groundwater contamination usually occurs because of damage to the landfill insulation or improper functioning of the landfill drainage system. An important aspect is the selection of the location of the landfill, taking into account topography, environmental and climatic conditions (Górecka, Koda, 2010; Klimek et al., 2010). The efficiency of the landfill structure, including sealing, which includes a natural and artificial barrier, remains significant (Wysocka, 2015).

2. Research methodology

The aim of the study was to analyse the efficiency of the structure of the operated municipal waste landfill based on the analysis of the composition of leachate and groundwater, and the hypothesis was that the design of the tested landfill minimizes the impact of stored waste on the quality of groundwater. The research facility is a municipal waste landfill located in south-eastern Małopolska. The facility has been operating since 1985 and non-hazardous and neutral waste is deposited there, with particular emphasis on fractions after secondary segregation.

Groundwater research in 2016-2020 included the analysis of the results from the piezometer P11 (20 tests – sector VI) in the inflow, as well as P13 (20 tests – sector VI) and P5 for the exploitation phase (20 tests – sector VI) and P6 for the phase post-exploitation (10 tests – sectors I-V) at the outflow.

Figure 1. Location of groundwater and leachate testing points in the area of the landfill (northeastern Małopolska, southern Poland)

Legend: P5 – groundwater outflow, P6 – outflow, P11 – inflow, P13 – outflow, SR3 – expansion well, PO1 – lower leachate tank, PO2 – upper leachate tank

The study of leachate water in the years 2016-2020 was carried out in the operational phase (20 measurements – closed sectors IV-V and active VI), and post-exploitation phase (10 measurements – closed sectors I-III) – in the PO1 leachate tank (lower) and the PO2 tank (upper) (closed sectors IV-V and open sectors VI) and the SR3 expansion well located 30 [m] before the first sewage well (Figure 1).

The scope of the research included the determination of physical and chemical parameters (10): pH, EC (electrolytic conductivity), TOC (total organic carbon), PAHs (polycyclic aromatic hydrocarbons) and Cr (chromium), Cu (copper), Zn (zinc), Cd (cadmium), Hg (mercury), Pb (lead). The collected samples of groundwater and leachate were sent to an accredited laboratory, and the test results were subjected to comparative analysis with the permissible limit values specified in the water law permit for leachate water (Rozkrut, 2021), Regulation (2019b) for sewage and leachate and in Regulation (2019a) for groundwater. Research including the identification of the composition of groundwater and leachates in the area of the landfill site, taking into account the indicated indicators, was conducted by Przydatek (2021).

3. Construction and operation of a landfill

From 1985 to the end of 2020, 1,302,634 [Mg] of waste was deposited in the landfill site consisting of six sectors. Sectors I-IV were closed after they were full until 2009. In turn, in 2017, in the closed sector V, on the contrary, from 2017 to 2020, 122,125 [Mg] of waste was deposited in the active sector VI (area 2.2 [ha]).

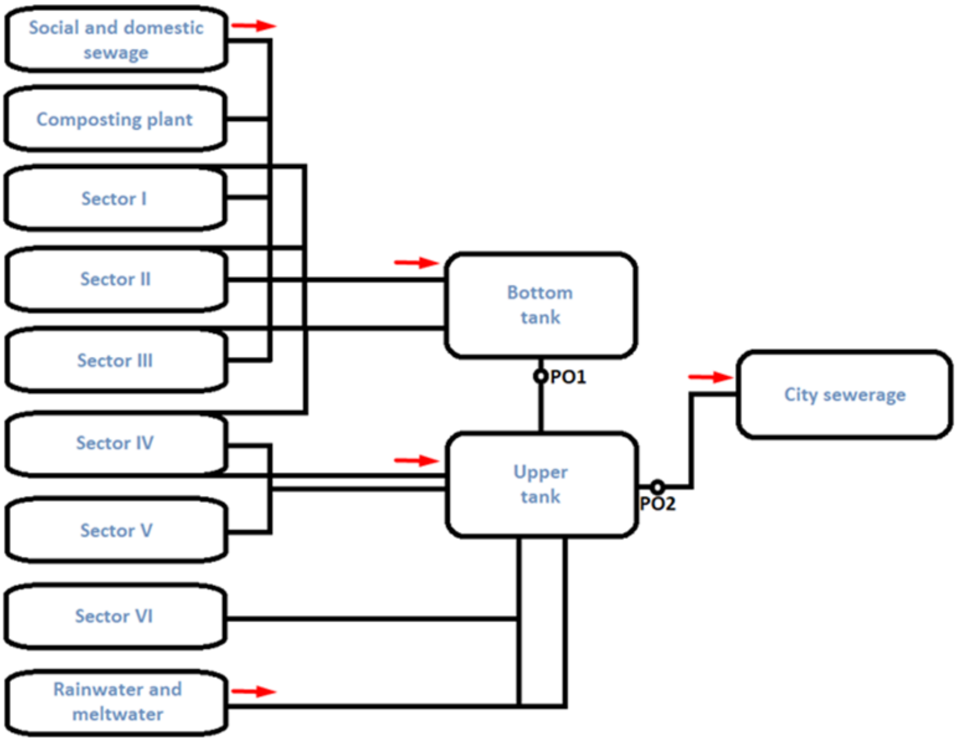

Figure 2. Scheme of water drainage from the landfill site

The analysed landfill has a seal, bottom, and slopes. The insulation was made of a polyethylene geomembrane with a thickness of 2 [mm] and a density of 0.942 [g·cm^{-3}] and a geotextile with a thickness of 8 [mm] and a density of 1200 [g·m^{-3}], as well as a layer of clay with a thickness of 1 [m].

After the closure process, the landfill is undergoing a recultivation process. After filling a given sector, it is covered with a reclamation layer composed of two parts: a 0.4 [m] thick sealing layer (mineral) of low-permeability soil and a 0.2 [m] thick soil-forming layer (mineral-humus). The thickness of the biological layer is up to 1 [m] for sowing and planting.

Drainage includes the intake of leachate water, its pre-treatment and discharge into the municipal sewage system. The sources of sewage are rainwater from closed sectors I-V, open sector VI, rainwater and meltwater (from roads and squares, composting plants and animal shelters), as well as social and domestic sewage from administrative and social buildings (Figure 2). The drainage system in the landfill consists of open and closed channels:

- drainage discharging leachate water into tanks;
- a perimeter ditch running along the dike of the entire perimeter of sectors V and VI;
- two leachate water reservoirs with pumping stations (the lower one for reclaimed sectors I-III and the upper one for closed sectors IV and V and active VI);
- control and expansion well.

4. Qualitative analysis of the composition of groundwater and leachate

Groundwater

The pH value in groundwater in the inflow was on average 7.4 [pH] and the results were in the range of 6.6-8.1 [pH]. However, in the outflow in the observation wells, the results were at the level of 6.7-8.2 [pH], with an average of 7.3-7.5 [pH].

In the piezometric well P11, the PEW concentration was in the range of 290-1,000 [μS · cm-1] with an average of 674 [μS · cm^{-1}]. At the outflow in P13, it ranged from 500 to 1,100 [μS · cm^{-1}] with an average value of 758 [μS · cm^{-1}]. For the exploitation phase, the average value was 1,114 [μS · cm^{-1}] with the results ranging from 600 to 1,621 [μS · cm^{-1}], and for the post-exploitation phase it was 1,178 [μS · cm^{-1}] in the range of 900-1,700 [μS · cm^{-1}].

However, the concentration of PAHs in all observation wells was 0.000002 [mg · dm^{-3}] throughout the entire research period. The situation was similar to the chromium concentration, which was recorded at 0.01 [mg · dm^{-3}].

The minimum value of zinc in all piezometers was 0.02 [mg · dm^{-3}]. However, the maximum in P11 was recorded at the level of 0.14 [mg · dm^{-3}], and in P13 it was 0.25 [mg · dm^{-3}]. However, the maximum value of zinc for the exploitation phase was 0.17 [mg · dm^{-3}], and for the post-exploitation phase it was 0.13 [mg · dm^{-3}]. The average in all observation wells was in the range of 0.04-0.06 [mg · dm^{-3}], including 0.04 [mg · dm^{-3}] in the inflow.

The lowest copper concentration in all piezometers was 0.005 [mg · dm^{-3}]. However, in the inflow, a maximum of 0.016 [mg · dm^{-3}] was recorded with an average of 0.006 [mg · dm^{-3}]. In the piezometric well P13, the average value was 0.006 [mg · dm^{-3}], while the maximum value was 0.023 [mg · dm^{-3}]. The average in P5 was 0.007 [mg · dm^{-3}] with a maximum value of 0.021 [mg · dm^{-3}]. In turn, the maximum result in P6 was recorded at 0.045 [mg · dm^{-3}], and the average result was 0.018 [mg · dm^{-3}].

The minimum value of cadmium in all piezometers was 0.0002 [mg · dm^{-3}], and the maximum in P11 and P5 - 0.001 [mg · dm^{-3}], in P13 - 0.005 [mg · dm^{-3}], and in P6 - 0.01 [mg · dm^{-3}]. The average at the inflow was 0.0006 [mg · dm^{-3}], at the outflow it was from 0.0004 to 0.0015 [mg · dm^{-3}].

The minimum lead concentration in all samples was 0.002 [mg · dm^{-3}], and the maximum was 0.01 [mg · dm^{-3}]. The average value over 5 years was 0.005-0.006 [mg · dm^{-3}]. The situation was similar with the mercury concentration, which amounted to 0.0001 [mg · dm^{-3}] in all observation wells. The average included concentrations in the range of 0.0006-0.0007 [mg · dm^{-3}].

Table 1
Composition of groundwater at the landfill in 2016-2020

Parameter	**Value**	**Inflow**	**Outflow**			**Poor chemical condition according to the Regulation (2019a)**
		P11	**P13**	**P5**	**P6**	
Reaction	Min [pH]	6.6	6.9	6.8	6.7	<6.5 and >9.5
	Max [pH]	8.1	8.1	8.2	8.0	
	Average [pH]	7.4	7.5	7.4	7.3	
EC	Min [µS · cm^{-3}]	290	500	600	900	< 3000
	Max [µS · cm^{-3}]	1,000	1,100	1,621	1,700	
	Average [µS · cm^{-3}]	674	758	1 114	1 178	
TOC	Min [mg · dm^{-3}]	2.55	4.81	11.9	10.8	**< 20**
	Max [mg · dm^{-3}]	30.8	19.6	48.3	40.6	
	Average [mg · dm^{-3}]	10.8	10.9	**22.1**	**19.0**	
PAHs	Min [mg · dm^{-3}]	0.000002	0.000002	0.000002	0.000002	< 0.0005
	Max [mg · dm^{-3}]	0.000002	0.000002	0.000002	0.000002	
	Average [mg · dm^{-3}]	0.000002	0.000002	0.000002	0.000002	
Cr	Min [mg · dm^{-3}]	0.01	0.01	0.01	0.01	< 0.1
	Max [mg · dm^{-3}]	0.01	0.01	0.01	0.01	
	Average [mg · dm^{-3}]	0.01	0.01	0.01	0.01	
Zn	Min [mg · dm^{-3}]	0.02	0.02	0.02	0.02	< 2
	Max [mg · dm^{-3}]	0.14	0.25	0.17	0.13	
	Average [mg · dm^{-3}]	0.04	0.06	0.04	0.05	
Cu	Min [mg · dm^{-3}]	0.005	0.005	0.005	0.005	< 0.5
	Max [mg · dm^{-3}]	0.016	0.023	0.021	0.045	
	Average [mg · dm^{-3}]	0.006	0.006	0.007	0.018	
Cd	Min [mg · dm^{-3}]	0.0002	0.0002	0.0002	0.0002	< 0.01
	Max [mg · dm^{-3}]	0.001	0.005	0.001	0.01	
	Average [mg · dm^{-3}]	0.0006	0.0008	0.0004	0.0015	
Pb	Min [mg · dm^{-3}]	0.002	0.002	0.002	0.002	< 0.1
	Max [mg · dm^{-3}]	0.01	0.01	0.01	0.01	
	Average [mg · dm^{-3}]	0.006	0.006	0.005	0.006	
Hg	Min [mg · dm^{-3}]	0.0001	0.0001	0.0001	0.0001	< 0.005
	Max [mg · dm^{-3}]	0.001	0.001	0.001	0.001	
	Average [mg · dm^{-3}]	0.0007	0.0007	0.0006	00007	

Leachate

The pH in the upper reservoir ranged from 7.5 to 8.6 [pH] with an average of 8.1 [pH], while in the lower reservoir, the range of results was 7.7-8.4 [pH] with an average value of 8 .0 [pH]. At the sewage intake point, i.e. in SR3, the results ranged from 7.7 [pH] to 9.1 [pH] with an average of 8.4 [pH].

In the PO1 tank, the PEW value was from 653 to 12,000 [μS · cm^{-3}], in PO2 from 907 to 11,390 [μS · cm^{-1}], and in SR3 from 601 to 12,000 [μS · cm^{-1}]. The average over the 5-years was: 6,575, 7,220, and 7,122 [μS · cm^{-1}], respectively, which means comparable results for leachates and sewage.

However, TOC results in samples from the upper reservoir included values in the range of 185-920 [mg · dm^{-3}] with an average value of 489.1 [mg · dm^{-3}], and in the lower reservoir from 178 to 853 [mg · dm^{-3}] at an average concentration of 391.3 [mg · dm^{-3}]. The average TOC concentration in the expansion well samples was 532 [mg · dm^{-3}] with values ranging from 262-1,627 [mg · dm^{-3}]. It should be emphasized that the average values of this indicator exceed the concentration permitted for wastewater – 30 [mg · dm^{-3}] specified in the Regulation (2019b).

The minimum value of PAHs in three measurement places was 0.000002 [mg · dm^{-3}]. However, the maximum value in PO2 was 0.00042 [mg · dm^{-3}], in PO1 it was 0.00037 and in SR3 it was 0.00083 [mg · dm^{-3}]. The average ranged from 0.00011 [mg · dm^{-3}] in the lower leachate tank to 0.00016 [mg · dm^{-3}] in the lower one and the expansion well.

The minimum chromium content in the places where leachates and sewage samples were taken was 0.01 [mg · dm^{-3}], and the maximum in PO2 was recorded at 0.45 [mg · dm^{-3}] with an average of 0.12 [mg · dm^{-3}]. However, the lowest average result in PO1 was 0.07 [mg · dm-3] and the highest was 0.15 [mg · dm^{-3}] with an average of 0.07 [mg · dm^{-3}]. In turn, in the SR3 expansion well, the maximum result was recorded at the level of 0.40 [mg · dm^{-3}] with the highest average of 0.14 [mg · dm^{-3}]. Average values at points PO2 and SR3 showed that the permissible values were exceeded (Rozkrut, 2021).

The zinc concentration results in the upper reservoir were in the range of 0.05-0.37 [mg · dm^{-3}] with an average of 0.11 [mg · dm^{-3}]. In the lower reservoir, an average result of 0.09 [mg · dm-3] was obtained, with results ranging from 0.02-0.32 [mg · dm-3]. In SR3, the zinc content was in the range of 0.05-0.81 [mg · dm^{-3}] with an average of 0.14 [mg · dm^{-3}].

The minimum copper content in leachate and sewage samples was 0.0005 [mg · dm^{-3}], while the maximum in tanks was 0.051-0.052 [mg · dm^{-3}], and in the expansion well the maximum was 0.067 [mg · dm^{-3}]. The highest average occurred at point SR3 - 0.022 [mg · dm^{-3}].

Throughout the entire research period, the content of cadmium and lead was 0.01 [mg · dm-3].

However, the mercury concentration in three measurement places was recorded from 0.0005 to 0.001 [mg · dm^{-3}]. In the upper reservoir, the average concentration was 0.0008 [mg · dm^{-3}], in the lower reservoir 0.0009 [mg · dm^{-3}], and the lowest in SR3 – 0.0006 [mg · dm^{-3}].

Table 2

Composition of leachate at the tested landfill in 2016-2020

Parameter	**Value**	**Collection point leachate**		**Collection point wastewater**	**Permissible values according to Rozkrut (2021), Regulation (2019b)**
		PO2	**PO1**	**SR3**	
Reaction	Min [pH]	7. 5	7. 7	7. 7	-
	Max [pH]	8. 6	8. 4	9. 1	
	Average [pH]	8. 1	8. 0	8. 4	
EC	Min [µS · cm^{-3}]	653	907	601	-
	Max [µS · cm^{-3}]	12,000	11,390	12,000	
	Average [µS · cm^{-3}]	6,575	7,220	7,122	
TOC	Min [mg · dm^{-3}]	185.0	178.0	262.0	< **30**
	Max [mg · dm^{-3}]	920.0	853.0	1,627.0	
	Average [mg · dm^{-3}]	**489.1**	**391.3**	**532.0**	
PAHs	Min [mg · dm^{-3}]	0.000002	0.000002	0.000002	< 0.0005
	Max [mg · dm^{-3}]	0.00042	0.00037	0.00083	
	Average [mg · dm^{-3}]	0.00011	0.00016	0.00016	
Cr	Min [mg · dm^{-3}]	0.01	0.01	0.01	< 0.1
	Max [mg · dm^{-3}]	0.45	0.15	0.40	
	Average [mg · dm^{-3}]	**0.12**	0.07	**0.14**	
Zn	Min [mg · dm^{-3}]	0.05	0.02	0.05	< 2.0
	Max [mg · dm^{-3}]	0.37	0.32	0.81	
	Average [mg · dm^{-3}]	0.11	0.09	0.14	
Cu	Min [mg · dm^{-3}]	0.005	0.005	0.005	< 0.5
	Max [mg · dm^{-3}]	0.052	0.051	0.067	
	Average [mg · dm^{-3}]	0.021	0.014	0.022	
Cd	Min [mg · dm^{-3}]	0.01	0.01	0.01	< 0.4
	Max [mg · dm^{-3}]	0.01	0.01	0.01	
	Average [mg · dm^{-3}]	0.01	0.01	0.01	
Pb	Min [mg · dm^{-3}]	0.01	0.01	0.01	< 1.0/0.5
	Max [mg · dm^{-3}]	0.01	0.01	0.01	
	Average [mg · dm^{-3}]	0.01	0.01	0.01	
Hg	Min [mg · dm^{-3}]	0.0005	0.0005	0.0005	< 0.06
	Max [mg · dm^{-3}]	0.001	0.001	0.001	
	Average [mg · dm^{-3}]	0.0008	0.0009	0.0006	

5. Discussion

The average value of the reaction in groundwater at the inlet and outlet was up to 7 [pH], which indicated a neutral reaction. Daniszewski and Draszawka-Bołzan (2012) similarly showed the neutral reaction of water and at the same time indicated its alkaline character in the post-exploitation phase of the landfill. The average PEW value was lower than in leachates, ranging from 674 [µS · cm^{-1}] at the inflow to 1,178 [µS · cm^{-1}] at the outflow. Grygorczuk-Petersons and Wiater (2012) showed, in similar conditions, a higher PEW 2340 result [µS · cm^{-1}]. Analysis of the composition of groundwater showed increased TOC concentrations in groundwater below the landfill. At the outflow, the average TOC concentration in the exploitation phase was higher by 11.3 [mg · dm^{-3}], and in the post-exploitation phase by 8.2 [mg · dm^{-3}] about to the one recorded at their inflow, which indicated the poor chemical condition of the water. Differently, Przydatek (2013) showed a lower average concentration of TOC at the outflow of water from a landfill in Masovia, which amounted to 5.4 [mg · dm^{-3}]. It should be emphasized that the microelement test results did not indicate that the permissible level was exceeded, at both the inflow and outflow. In turn, some researchers (Grygorczuk--Petersons, Wiater, 2012) detected increased mercury and cadmium content in water in the area of the landfill.

The analysis of the composition of sewage and leachate confirmed that in the case of pH, the results ranged from 6.7 to 8.2 [pH], which indicated the occurrence of a neutral and alkaline reaction (Koc-Jurczyk, Różak, 2011). The latter result according to Jagiełło (2003) indicates that the landfill has been in use for over 10 years. Other researchers Przydatek (2012) and Żelezik (2015) obtained the reaction in leachates with the values of; 7.3-7.6 [pH] and 7.6-7.7 [pH]. The results of specific electrolytic conductivity ranged from 6,575 to 7,220 [µS · cm^{-3}], which may be due to the dilution of leachates with rainwater (Żelezik, 2015). However, the average TOC content in the tested leachate samples ranged from 391.3 to 532 [mg · dm^{-3}], which exceeded the permissible level (Regulation, 2019b). Melnyk et al. (2014) showed lower TOC concentrations in a landfill. The increased concentration of chromium recorded in two leachate test points confirms that the source of this contamination may be pigment or leather waste, which is a carcinogenic factor (Kim et al., 2015). The concentration of other heavy metals Zn, Cu, Cd, Pb and Hg in the tested leachates was low. According to Tałałaj (2014) low concentration of heavy metals in leachates may result from the formation of stable organic complexes by the metals. Some researchers (Melnyk et al., 2014) used toxicity tests to identify the impact of stored waste on the aquatic environment, which they considered an excellent complement to the monitoring system based mainly on chemical indicators.

6. Summary and conclusions

The analysis of physical and chemical indicators of groundwater, sewage, and leachate showed that in the vast majority of results, the permissible level was not exceeded. However, qualitative analysis of leachate water showed increased TOC and chromium concentrations. The average TOC content in the tested leachate samples ranged from 391.3 to 532 [mg · dm^{-3}], showing exceedances. Similarly, the analysis of the composition of groundwater confirmed that TOC concentrations in groundwater downstream of the landfill in the exploitation and post-exploitation phases were higher by 11.3 [mg · dm^{-3}] and 8.2 [mg · dm^{-3}], respectively, than in the inflow. It should be noted that the test results for microelements in leachate and water did not indicate that the permissible level was exceeded.

To sum up, the results of the analysis indicate the possibility of limited effectiveness of the barrier sealing the bottom of the landfill site, which confirms the impact of leachate on the aquatic environment; it is advisable to expand the scope of research to include toxicity tests for both leachates and groundwater.

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