

GROUNDWATER AND SURFACE WATER QUALITY ASSESSMENT NEAR THE CLOSED MUNICIPAL LANDFILL

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Received: 2013.05.19

Accepted: 2013.06.13

Published: 2013.07.10

ABSTRACT

During the current research the level of groundwater (piezometers P2,P3,P4) and surface water (reservoir B) contamination during landfill operation and after its closure were examined. 113 samples of groundwater and surface water were collected from spring 2005 until spring 2012, i.e. three years after the landfill closure. The samples were analyzed for pH, EC, PAH, TOC and six heavy metals: Cr, Hg, Zn, Pb, Cd, Cu. The heavy metal concentration in groundwater and surface water both during landfill operations and after the landfill closure remained on a similar level and did not exceed permissible levels determined by WHO. Cr was an exception, because its concentration, during landfill exploitation, reached the value of 0.028 mg/l in surface water. In all examined after the landfill was closed a decrease in the EC value was observed. With the landfill closure the TOC concentration in groundwater increased from 1.8–3.4 to 2.07–3.6 mg/l and the PAH concentration from 0.01 to 0.02 mikrog/l. It may be attributed to a slowdown of decomposition in landfill. An additional PAH source for ground and surface water are surface run-offs from road pavements, yards and parking lots. The remaining high TOC level in a surface reservoir after the landfill closure is also a result of eutrophication, which enriches water with organic substances. Seasonal changes in the concentration of pollutants were observed, resulting both from their dilution by atmospheric precipitation (EC, pH, Cd, Cu) and due to washing them out from neighboring areas and enriching with them the analyzed water (Cu, PAH, Hg).

Keywords: groundwater, landfill impact, monitoring, pollution, surface water.

INTRODUCTION

Landfilling of municipal solid waste is one of the cheapest methods for organized waste management in many parts of the world [Longe and Balogun 2010, Jhamnani and Singh 2009]. That is why over the past decades, landfills have always been the dominant technology for municipal solid waste disposal [Xing et al. 2013, Manfredi and Christensen, 2009, Manfredi et al. 2010]. One of the products which is produced by dumping sites is the leachate that migrates to adjacent areas, resulting in a gross pollution of soil, surface water and groundwater [Bocanegra et al. 2000]. The scale of this threat depends on the composition and quantity of the leachate and geological and hydro-geological circumstances of the

area close to a landfill [Longe and Balogun 2010, Słomczyńska and Słomczyński 2004]. Municipal landfill leachate are highly concentrated complex effluents, which contain dissolved organic matters, inorganic compounds, such as ammonium, calcium, magnesium, sodium, potassium, iron, sulfates, chlorides and heavy metals such as cadmium, chromium, copper, lead, nickel, zinc, and xenobiotic organic substances [Christensen et al. 2001, Bhalla et al. 2012, Ogundiran and Afolabi 2008]. The composition of landfill leachate and its amount depends on several factors, such as waste composition, degree of compaction, absorptive capacity of the waste, age of a waste, the climate, level of precipitation, engineering and operational factors of a landfill [Bhalla et al. 2012, Longe and Balogun 2010]. As a result of leachate leach-



ing into water a contamination plume has formed, and it has been described in various case studies [Bocanegra et al. 2000, Christensen et al. 2001, Mor et al. 2006]. According to Bilgili et al. [2006] physical, chemical and biological processes, which occur within a conventional landfill, result in production of the leachate for a very long time, even after a landfill closure. The long-term environmental impacts caused by a leachate may last for several centuries [Bilgili et al. 2006, Cossu et al. 2003]. So, groundwater and surface water occurring near closed landfills are subjected to infiltration of a very contaminated water from improperly sealed or not sealed dumping sites or from surface run-offs from landfill areas.

In Poland a number of municipal landfills were built in 1980's and 1990's. As there was no appropriate regulations and guidelines; these landfills were built most often without presently required protection against their negative impact on the environment i.e. without artificial sealing with a geomembrane, without draining the leachate and without a biogas collection system. A simple layer of clay or any other geological material at the bottom of a potential landfill functioned as a layer sealing the substrate. Only after the adoption of the Act on Waste in 2001 and after Poland joined the EU, municipalities started to provide new landfills with full protection systems and the old ones – still operating – were provided with piezometers to monitor the quality of ground water. In 2008 it was decided to close landfills without required protections against a negative impact on the environment. As a result, the number of landfills operated in Poland decreased from 879 in

2008 to 578 in 2011. Thus, more than 300 closed landfills started appeared, which due to biological and physicochemical processes occurring in waste and the lack of proper seal still pose a threat, especially to the ground waters. Additionally, the provision of low permeability landfill cover increase run-off and the possibility of contaminations to get to/migrate to adjacent land to the ground and water environment.

This work presents the groundwater and surface water quality assessment near a closed municipal landfill in Warminsko-Mazurskie Voivodeship in the north-eastern Poland.

MATERIAL AND METHODS

Area of study

The analyzed landfill is situated in Warminsko-Mazurskie Voivodeship in north-eastern Poland. Its operation started in 1983. In the landfill municipal waste is deposited: apart from fluid waste, hazardous substances, explosive, radioactive and toxic waste. Till 2010 waste was stored on a 7.7 ha (Cell A) quarter (Figure 1).

The quarter (Cell A) is sealed with a natural 31-meter clay substrate functioning as a geological barrier. In order to protect the ground-and-water environment a circumferential ditch to prevent contaminated water from getting out of the landfill area was constructed. In 2005 in the landfill 4 piezometers (P1, P2, P3, P4) were installed from which 3 piezometers (P2, P3, P4) are still working. In 2010 the operation of the Cell A was stopped and reclamation works as well as works



Fig. 1. Location of the landfill and sampling points



to construct a new dumping quarter were started. It is estimated that in the closed quarter (Cell A) 550,000 Mg of waste was deposited. In a direct vicinity of the landfill there is a surface water reservoir left after a clay exploitation hollow.

The landfill area is situated on glacial clays covered with kame hills. Glacial clays lie at the depth of 31–56 m. In the land under study two water-bearing layers were found:

- inter-clay waters – found in the P4 piezometer – the water-bearing layer constitute sand lens occurring at various depths. A complex of glacial clays of a thickness above 50 m constitute the insulation of the water-bearing layer. Water runs off in S-E and S direction.
- intermoraine waters – found out in the P2 and P3 piezometers – fine and medium sands constitute a water-bearing layer. A complex of glacial clays of a thickness above 49.5 m constitute the insulation of the water-bearing layer. The insulation of this layer is a complex of boulder clays whose thickness does not exceed 49.5 m. The run-off direction of waters is S. Piezometr P2 is situated at the inflow of groundwater to the landfill and it was taken as a pollution background.

Details of the sampling points are presented in Table 1.

Average rainfall in this region is about 650 mm annually. Approximately 40% of the rainfall occurs in the summer season, 23% – in autumn season, 15 % – in winter, and 22% – in spring. Average annual temperature is about 8 °C.

METHODS

Groundwater and surface water data were collected from spring 2005 until spring 2012, i.e. three years after closing Cell A. Sampling was done four times a year in each season. On the whole, during the research, 113 samples (twenty eight for the P2 and P4 piezometers, twenty

seven for the P3 piezometer and thirty eight for the surface water) were taken. The samples were analyzed – according to the Polish Regulatory of Landfill Monitoring (Journal of Laws 2001.220.1858) – for pH, electroconductivity (EC), Polycyclic Aromatic Hydrocarbons (PAH), Total Organic Carbon (TOC) and six heavy metals: Cr, Hg, Zn, Pb, Cd, Cu. Collected groundwater and surface water samples were transported to the laboratory and stored at 4 °C. The analyses were done in commercial and accredited laboratory of Regional Inspectorate of Environmental Protection in Olsztyn and Giżycko. Since 2010 analyses were done in the accredited laboratory SGS EKO-PROJEKT. Determinations were carried out according to the Polish Standards. Determination of pH and EC were performed on the same day when samples were collected, using a potentiometric method for pH (according to PN90/C-04540-01) and conductometric methods for EC (PN-EN 27888:1999). The samples for metal analyses were preserved by adding HNO₃. The heavy metals – except for Hg – were analyzed by atomic emission spectrophotometry ICP-OES (PN-EN ISO 11885:2009), Hg was determined by an atomic fluorescence spectrometry (PN-EN ISO 17852:2009). TOC was analyzed with the help of an infrared spectrometry method (PN-EN:1484:1999) and PAH using a liquid chromatography (HPLC) (PB-01/2006/Pel). The obtained results were the mean value of three determinations carried out simultaneously.

Data analysis included a mean, minimum, maximum, standard deviation, t-Student test to analyze differences in the groundwater quality before and after closure of the Cell A and the analysis of seasonal effect on the groundwater quality.

RESULT AND DISCUSSION

Analytical results of physicochemical characteristics of groundwater and surface water samples are presented in Table 2 and Figure 2.

Table 1. Sampling points location and theirs characteristics

Sample	Type	Location	Distance From Cell A (m)	Depth to Water Level in Wells (m)
P2	groundwater	inflow (background)	250	28
P3	groundwater	outflow	180	34
P4	groundwater	outflow	320	14
B	surface water	standing water	60	-



Table 2. Physico-chemical characteristics of analyzed groundwater and surface

Parameter		Groundwater				Surfacewater	WHO/PL standards for drinking water quality
		P2 inflow	P3 outflow	P4 outflow	outflow average (P3, P4)	B	
pH	Mean	7.21	7.26	7.14	7.20	8.39	-
	N	28	27	28	55	38	
	St. Dev.	0.240	0.236	0.246	0.247	0.423	
	Min	6.71	6.71	6.58	6.58	7.00	
	Max	7.73	7.77	7.73	7.77	9.09	
EC ($\mu\text{S}/\text{cm}$)	Mean	695.5	664.6	1,141.3	907.3	3,098.9	-
	N	28	27	28	55	36	
	St. Dev.	76.54	76.70	108.53	257.96	1822.22	
	Min	383.0	360.0	870.0	360.0	225.0	
	Max	794.0	756.0	1,252.0	1,252.0	7,660.0	
Cd (mg/l)	Mean	0.0005	0.0007	0.0005	0.0006	0.0005	0.003/0.005
	N	27	26	27	53	35	
	St. Dev.	0.0004	0.0006	0.0004	0.0005	0.0004	
	Min	0.00005	0.00005	0.00005	0.00005	0.00005	
	Max	0.0010	0.0029	0.0010	0.0029	0.0017	
Cu (mg/l)	Mean	0.0035	0.0021	0.0018	0.0019	0.0042	2.0/2.0
	N	28	27	28	55	36	
	St. Dev.	0.0038	0.0019	0.0015	0.0017	0.0036	
	Min	0.0005	0.0005	0.0005	0.0005	0.0010	
	Max	0.0140	0.0100	0.0079	0.0100	0.0160	
Zn (mg/l)	Mean	0.0300	0.0273	0.0269	0.0271	0.0336	-/5.0
	N	28	27	28	55	36	
	St. Dev.	0.0247	0.0204	0.0190	0.0195	0.0421	
	Min	0.0014	0.0050	0.0050	0.0050	0.0050	
	Max	0.1000	0.0910	0.0830	0.0910	0.2248	
Cr (mg/l)	Mean	0.0022	0.0022	0.0024	0.0023	0.0055	0.005/0.05
	N	28	27	28	55	36	
	St. Dev.	0.0020	0.0020	0.0021	0.0020	0.0061	
	Min	0.0003	0.0003	0.0003	0.0003	0.0005	
	Max	0.0050	0.0050	0.0056	0.0056	0.0280	
Pb (mg/l)	Mean	0.0036	0.0043	0.0028	0.0036	0.0032	0.001/0.025
	N	28	27	28	55	36	
	St. Dev.	0.0027	0.0044	0.0014	0.0033	0.0024	
	Min	0.0005	0.0005	0.0005	0.0005	0.0005	
	Max	0.0100	0.0210	0.0060	0.0210	0.0090	
Hg (mg/l)	Mean	0.0001	0.0001	0.0001	0.0001	0.0001	0.006/0.001
	N	28	27	28	55	37	
	St. Dev.	0.0001	0.0001	0.0001	0.0001	0.0001	
	Min	0.0000	0.0000	0.0000	0.0000	0.0000	
	Max	0.0003	0.0003	0.0003	0.0003	0.0005	
PAH ($\mu\text{g}/\text{l}$)	Mean	0.0139	0.0135	0.1995	0.1084	0.0147	-
	N	25	24	25	49	27	
	St. Dev.	0.011	0.011	0.659	0.475	0.011	
	Min	0.003	0.003	0.005	0.003	0.003	
	Max	0.030	0.030	2.876	2.876	0.030	
TOC (mg/l)	Mean	2.04	1.95	3.48	2.73	40.95	-
	N	29	28	29	57	33	
	St. Dev.	2.19	1.75	3.13	2.64	28.66	
	Min	0.50	0.50	0.00	0.00	2.00	
	Max	9.86	7.73	13.60	13.60	102.00	



The reaction (pH) of the examined groundwater ranged from 6.6 in the piezometer P4 to 7.8 in the P3 piezometer with the mean value of 7.2 in the inflow and outflow waters. The pH of the surface water fluctuated from 7 to 9.1 with the mean value of 8.4. The increase in the pH in the surface reservoir can be a result of its eutrophication. An excessive development of algae causes an increase in the photosynthesis intensity and the consumption of a substantial amount of CO₂. The conductivity of groundwater ranges from 360 μS/cm (P3) to 1,252 μS/cm (P4) with the mean of 695.5 μS/cm for inflow-water (P2) and 907.3 μS/cm for outflow-waters (P3, P4). The average conductivity of surface waters was 3,098.9 at that time (within the range of 1,252–7,660 μS/cm). Fluctuations of EC in surface waters indicate a greater susceptibility of these waters to external factors and to inflow of contaminations from the landfill.

The WHO permissible level for all analyzed heavy metals in surface water and groundwater during the analyzed period was not exceeded. The Cd levels ranged from 0.00005 mg/l in P2 to 0.0029 mg/l in P3 with the mean value of 0.0005 mg/l in P2 (inflow) and 0.0006 mg/l in outflow waters. The Cd mean value in surface water was 0.0005 mg/l (0.00005–0.0017 mg/l) and was close the content of this element in ground waters. Cadmium usually precipitates quickly as a carbonate or is subject to absorption by hydroxides and metal oxides. According to Skorbilowicz, M. and Skorbilowicz, E. [2010] in the vicinity of industrial centres in river deposits there are more Cd amounts than in water. The maximum concentration of Cd both in ground and in surface water occurred at the same time (September 2005) and the reason for this is unknown. It could be a result of contamination of samples when sampling, of an improper transport of these or errors at measurements or readings. In ground water concentration of Cu occurred within a range of 0.0005 mg/l (P2) to 0.1 mg/l (P3) with the mean value of 0.003 mg/l in the inflow and 0.006 mg/l in the outflow. The average Cu content in surface waters was 0.004 mg/l and ranged from 0.001 to 0.016 mg/l. Observing changes of the Cu concentration in analyzed waters its cyclic fluctuations are visible (Figure 2). Probably an additional source of Cu in examined water are chemical fertilizers and pesticides applied on lands adjacent to the landfill. The Cr content in surface water ranged between 0.003 mg/l (P2, P3, P4) and 0.0056 mg/l in P4. Average

Cr concentration in all piezometers was similar amounting to 0.0022 mg/l in P2, P3 and 0.0024 mg/l in P4. In surface waters the fluctuations of Cr concentration were wider: from 0.0005 mg/l to 0.028 mg/l at the mean level of 0.0055 mg/l. The source of chrome in surface water could have been surface run-offs from the waste landfill. A higher Cr concentration in surface waters can also result from contamination in the form of a dust precipitation generated during operation of the landfill. After closure of the landfill the concentration of the Cr in surface waters decreased. The Zn concentration in ground water remained at a similar level of 0.0014 (P2) to 0.1 mg/l (P2). The average Zn concentration in inflow waters was 0.030 mg/l, and in outflow waters 0.027 mg/l. Slightly higher concentration of Zn was observed in surface water, were the Zn concentration oscillated between 0.005 and 0.224 mg/l at a mean value of 0.036 mg/l. According to Singh et al. (2008) the increased Zn concentration may be due to the presence of Z- based waste, such as zinc plated materials, fertilizers and cement. The average Pb concentration in inflow and outflow waters was the same, amounting to 0.0036 mg/l. Concentration of Pb in surface waters was at a similar level at a mean value of 0.0032 mg/l. For Hg in all analyzed water the concentration was < 0.0002 mg/l.

A low degree of groundwater contamination with heavy metals results from the geological structure of the ground under the landfill. The clay layer exceeding at some places even 50 m is a physical barrier restricting the migration of contaminations. It is also a barrier where contaminations can be stopped due to the process of sorption. This sealing and sorptive action of the clay layer can be seen well in case of the TOC. The average TOC value in ground water is similar: 1.94 mg/l (P3) to 3.48 mg/l (P4). In surface water average TOC concentration is 40.05 mg/l, with its source being both surface run-offs from the landfill and the eutrophication process, which additionally enriches water with organic substances produced by algae. The mean concentration of PAH in inflow was 0.014 μg/l (P2) and 0.11 μg/l in outflow water. The highest PAH concentration was recorded in the P4 piezometer closest to the landfill. The P4 piezometer inlet is situated on the road to the landfill and it does not rise above the ground surface. It is possible that surface run-offs from the road surface get into the piezometer through its inlet and reach groundwater. The

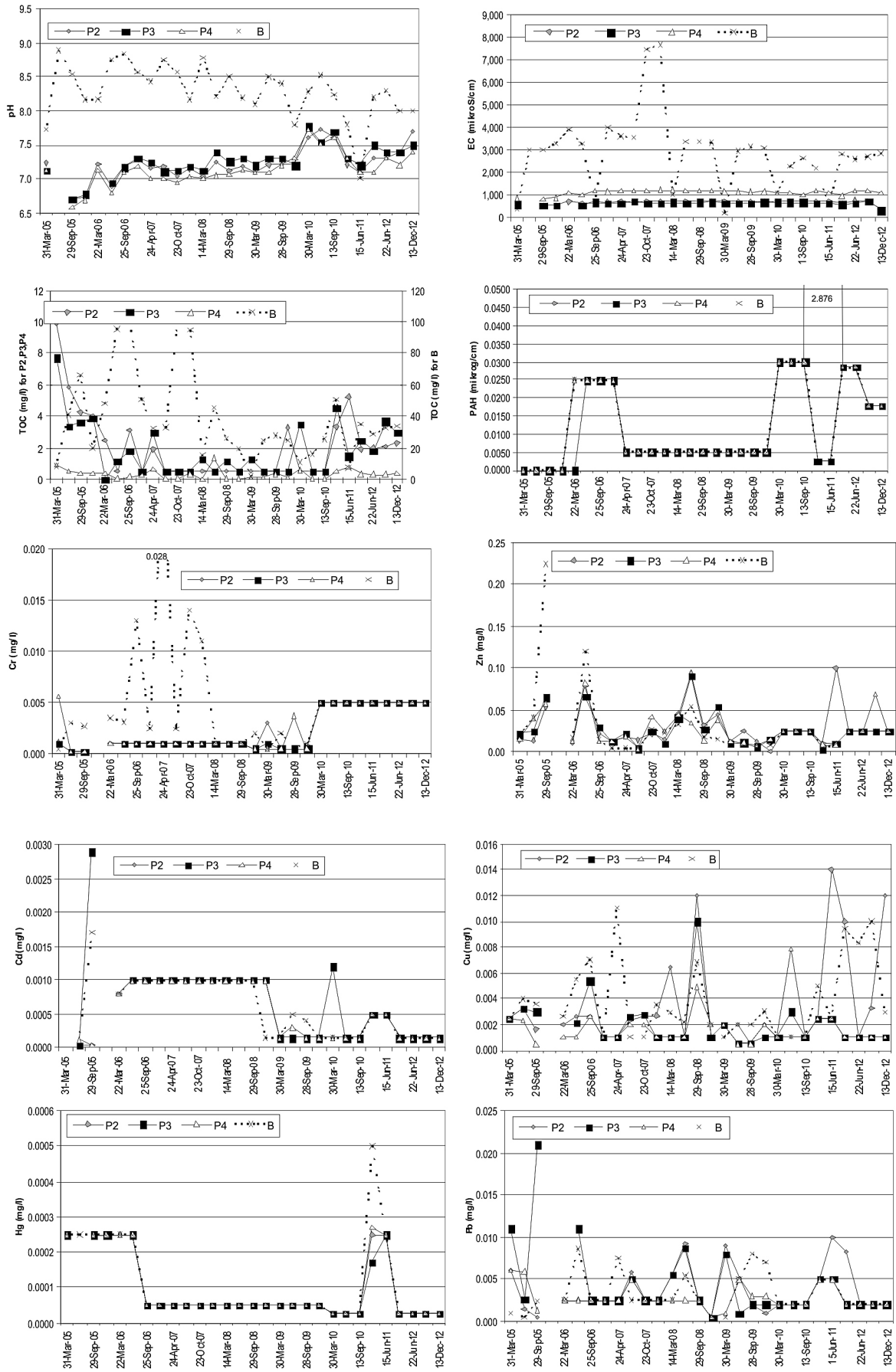


Fig. 2. Characteristics of groundwater and surface water quality during 2005–2012 years



Table 3. The results of t-Student test for groundwater (P2, P3, P4) and surface water (B)

P2	Mean		t	df	p	N		Standard deviation	
	during exploitation	after exploitation				during exploitation	after exploitation	during exploitation	after exploitation
pH	7.1771	7.4250	-2.023	26	0.053	24	4	0.23	0.19
EC (μ S/cm)	703.7	646.5	1.408	26	0.171	24	4	44.76	183.37
Cd (mg/l)	0.0006	0.0002	2.150	25	0.041	23	4	0.000	0.000
Cu (mg/l)	0.0029	0.0066	-1.863	26	0.074	24	4	0.003	0.005
Zn (mg/l)	0.0308	0.0250	0.430	26	0.671	24	4	0.027	0.000
Cr (mg/l)	0.0018	0.0050	-3.595	26	0.001	24	4	0.002	0.000
Pb (mg/l)	0.0036	0.0036	0.031	26	0.976	24	4	0.003	0.003
Hg (mg/l)	0.0001	0.0000	1.658	26	0.109	24	4	0.000	0.000
PAH (μ g/l)	0.0121	0.0233	-1.943	23	0.064	21	4	0.011	0.006
TOC (mg/l)	2.0312	2.0750	-0.036	27	0.971	25	4	2.369	0.171
P3	Mean		t	df	p	N		Standard deviation	
	during exploitation	after exploitation				during exploitation	after exploitation	during exploitation	after exploitation
pH	7.23	7.45	-1.790	25	0.086	23	4	0.240	0.057
EC (μ S/cm)	675.0	605.2	1.742	25	0.094	23	4	45.98	173.06
Cd (mg/l)	0.0008	0.0002	1.958	24	0.062	22	4	0.001	0.000
Cu (mg/l)	0.0022	0.0010	1.191	25	0.245	23	4	0.002	0.000
Zn (mg/l)	0.0277	0.0250	0.236	25	0.815	23	4	0.022	0.000
Cr (mg/l)	0.0017	0.0050	-3.614	25	0.001	23	4	0.002	0.000
Pb (mg/l)	0.0048	0.0020	1.168	25	0.254	23	4	0.005	0.000
Hg (mg/l)	0.0001	0.0000	1.582	25	0.126	23	4	0.000	0.000
PAH (μ g/l)	0.0115	0.0233	-2.074	22	0.050	20	4	0.011	0.006
TOC (mg/l)	1.8138	2.7500	-0.992	26	0.331	24	4	1.836	0.802
P4	Mean		t	df	p	N		Standard deviation	
	during exploitation	after exploitation				during exploitation	after exploitation	during exploitation	after exploitation
pH	7.12	7.25	-1.005	26	0.324	24	4	0.257	0.129
EC (μ S/cm)	1,142.2	1,135.8	0.107	26	0.915	24	4	112.07	98.29
Cd (mg/l)	0.001	0.000	2.251	25	0.033	23	4	0.000	0.000
Cu (mg/l)	0.002	0.001	1.103	26	0.280	24	4	0.002	0.000
Zn (mg/l)	0.025	0.036	-1.041	26	0.308	24	4	0.018	0.022
Cr (mg/l)	0.002	0.005	-3.046	26	0.005	24	4	0.002	0.000
Pb (mg/l)	0.003	0.002	1.292	26	0.208	24	4	0.002	0.000
Hg (mg/l)	0.000	0.000	1.651	26	0.111	24	4	0.000	0.000
PAH (μ g/l)	0.233	0.023	0.576	23	0.570	21	4	0.716	0.006
TOC (mg/l)	3.466	3.600	-0.078	27	0.938	25	4	3.37	0.535
B	Mean		t	df	p	N		Standard deviation	
	during exploitation	after exploitation				during exploitation	after exploitation	during exploitation	after exploitation
pH	8.43	8.13	1.362	36	0.182	34	4	0.43	0.15
EC (μ S/cm)	3,141.2	2,760.0	0.390	34	0.699	32	4	1,931	126.4
Cd (mg/l)	0.001	0.000	1.922	33	0.063	31	4	0.000	0.000
Cu (mg/l)	0.004	0.008	-2.175	34	0.037	32	4	0.003	0.003
Zn (mg/l)	0.035	0.025	0.430	34	0.670	32	4	0.045	0.000
Cr (mg/l)	0.006	0.005	0.187	34	0.853	32	4	0.006	0.000
Pb (mg/l)	0.003	0.002	1.028	34	0.311	32	4	0.003	0.000
Hg (mg/l)	0.000	0.000	1.412	35	0.167	33	4	0.000	0.000
PAH (μ g/l)	0.013	0.023	-1.734	25	0.095	23	4	0.011	0.006
TOC (mg/l)	42.103	32.625	0.614	31	0.544	29	4	30.437	2.8453

PAH concentration was higher during the landfill operation, which can mean that fuel spills from vehicles arriving at the landfill could have been its source. The average PAH concentration in surface waters was 0.014 $\mu\text{g/l}$, i.e. it was at the level of the concentration observed in groundwater in P2 and P3 piezometers.

In order to evaluate the change in the quality of ground and surface water before and after landfill closure, the t-Student test was carried out – for results see Table 3. In case of groundwater and surface water an improvement of the water quality after landfill closure was observed for Cd, Pb, Hg, EC, however, only the decrease in the Cd concentration was statistically significant; this was from 0.0006 to 0.0002 mg/l w P2, from 0.0008 to 0.0002 mg/l in P3 and from 0.001 to 0.000 mg/l in P4. Despite stopping waste disposal, the TOC level in groundwater was still similar and in case of the P3 it increased from 1.8 to 2.75 mg/l and in P4 from 3.46 to 3.60 mg/l. In surface water the TOC value decrease by about 25%, i.e. from 40.10 to 32.6 mg/l. The PAH concentration in surface water increased from 0.012 to 0.023 $\mu\text{g/l}$ in P2, from 0.01 to 0.02 $\mu\text{g/l}$ in P3 and from 0.012 to 0.023 $\mu\text{g/l}$. The increase in the PAH and TOC concentration after the landfill closure may be attributed to a slowdown of decomposition in the landfills. This supports the argument that PAH and TOC are long life pollutants in leachate and that PAH and TOC contents gradually increase in time. Similar mechanism for nitrogen was observed by Kim and Lee [2009]. In all piezometers also the Cr concentration increased: from 0.001 to 0.005 in P2, from 0.001 to 0.005 in P3, from 0.002 to 0.005 in P4. The author explains, however, that that it was caused by changing a laboratory, where samples were determined and where the sensitivity / accuracy of instruments for the analysis of the Cr was different. The concentration of other contamination indicators remained at a similar level.

Seasonal changes in the quality of groundwater and surface water were also analyzed – for results see Figure 3. The highest pH value and the lowest EC were observed in summer during the most intensive rainfalls. This is a common phenomenon, where a decrease in the conductivity is a response to a decrease in the concentration of major components, such as Na, K, Ca, HCO_3 and Cl through dilution by rainwater [Ettler et al. 2008]. Similar behavior can be observed for Cd, Cu and for TOC in surface water. In case of Cu

an increase in its concentration in spring season is observed. This phenomenon is due to rinsing out from areas adjacent to the landfill chemical fertilizer and liquid manure, which contain even up to 2000 mg Cu/kg, dry mass [Skorbiłowicz 2010]. The change in the concentration of Zn, Pb, Cr with an increasing trend during precipitations in summer cannot be explained by a simple hydrological mechanism. This phenomenon probably results from more complex geochemical/mineralogical reactions, which may include desorption or dissolution of solid phases in the landfill or in the bottom sediments in the stream downgradient in the landfill [Ettler et al. 2008]. In case of the Hg and PAH concentration, there are two peaks: one in summer and the other – in winter. The increase of their concentration is related to atmospheric precipitation and winter/spring time thaws, which wash away pollutants from the surfaces of roads, squares and parking lots, causing water contamination.

CONCLUSIONS

The heavy metal concentration in groundwater and surface water both during operation of the landfill and after its closure did not exceed permissible levels determined by WHO. Cr is an exception; its concentration in surface water during operation of the landfill reached a level of up to 0.028 mg/l (with the mean value of 0.006 mg/l during landfill operation/exploitation and 0.005 mg/l after the landfill closure). An effective protection against infiltration of contaminations to the ground substrate is the 50 m thick clay layer, where sorption of contaminations can occur.

The contamination of surface waters is due mainly to surface run-offs both from the landfill area and from adjacent land and to dust precipitation during operation of the landfill. An additional source of contamination is the process of eutrophication enriching surface water with organic substances. The evidence of that is a permanent high TOC level after the closure of the landfill as well as pH level higher than in case of groundwater, which is an evidence of a CO_2 consumption in the process of photosynthesis.

In all examined waters after the landfill closure a decrease of EC value was observed. After completion of landfill exploitation an increase in PAH and TOC concentration in case of groundwater and an increase in PAH concentration in



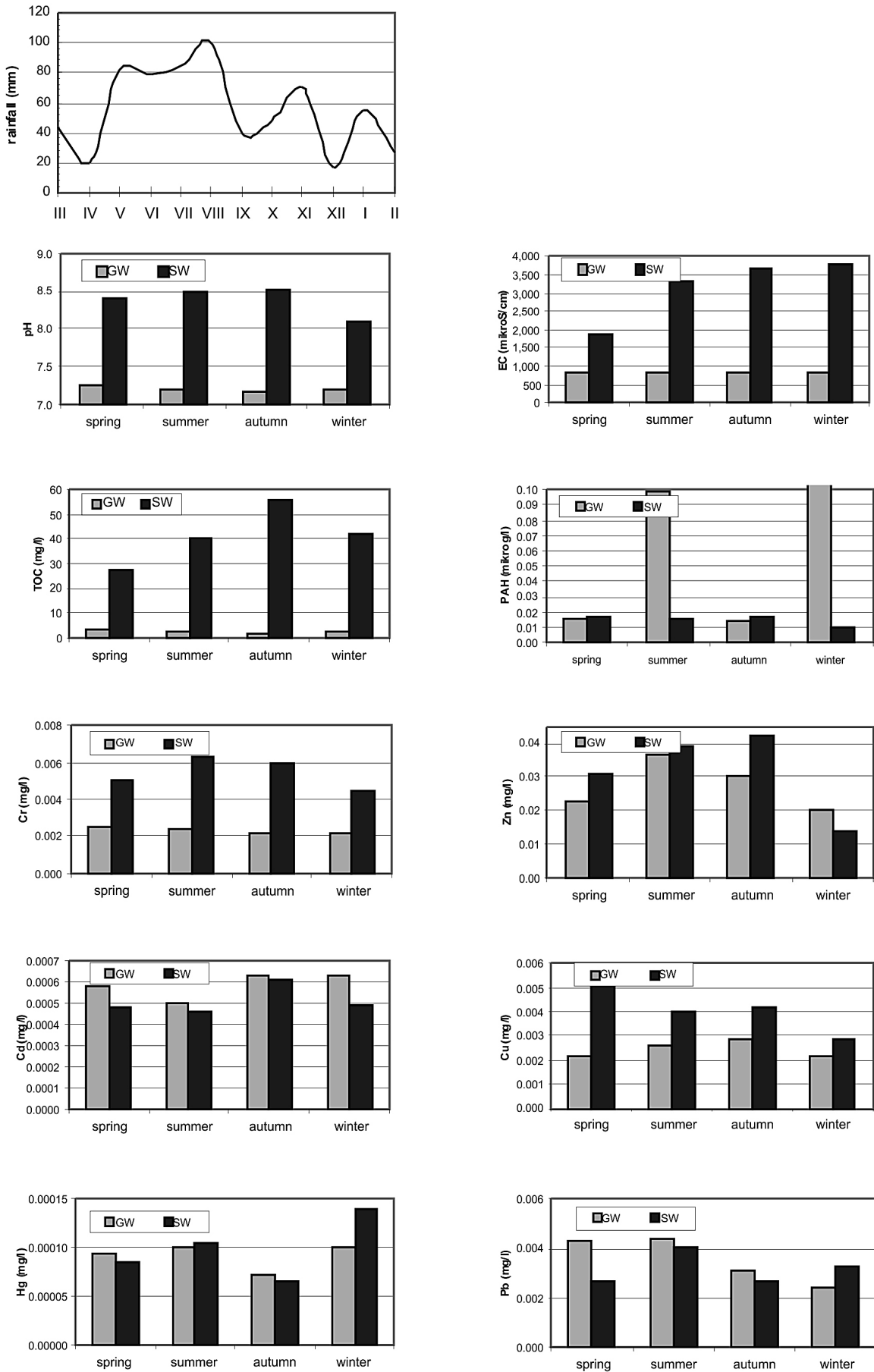


Fig. 3. Seasonal changes in water quality

case of surface water were observed. This may be attributed to the slowdown of decomposition in the landfills. This supports the argument that PAH and TOC are a long life pollutants in the leachate and that PAH and TOC content gradually increases in time. An additional PAH source for ground and surface water were surface run-offs from road surfaces, yards and parking lots, which occurred mainly during intensive atmospheric precipitations in summer and during winter/spring time thaws. Atmospheric precipitations cause the decrease of Cd, Cu, EC value and the increase of pH due to dilution. The increase in the Cu concentration in analyzed waters in spring time results from washing out chemical fertilizers and liquid manure, which contain a large content of Cu, from adjacent land. The change in the concentration of Zn, Pb, Cr with an increasing trend during precipitation results from more complex geochemical/mineralogical reactions, which may include desorption or dissolution of solid phases in the landfill or in the bottom sediments in the stream downgradient in the landfill.

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