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Impact of landfilling of red mud waste on local environment – the case of Górka

Introduction

Red mud is a highly alkaline (pH in the 10.5–13 range) by-product of bauxite processing. It is usually treated as a waste and is typically stored in large lagoons or in land-based disposal pits, depending on the method of bauxite processing (Feigl et al. 2012). Storage of this unutilized red mud takes vast tracts of usable land and pollutes (threat to water, land and air) and even can lead to environmental disaster, i.e. on October 4th 2010 in Hungary, tailings pond failed and about 1 million m^3 of sludge flooded the area, killing 10 people and damaging hundreds of houses in Ajka (www.enfo.hu). The worldwide scale is significant, as Power et al. (Power et al. 2011) estimated that 2.7 billion tons of red mud was stored.

The red mud disposal is not only an environmental problem, but it is economically problematic due to the costs of the realization and maintenance of containment structures and implies environmental problems for the storage site (huge areas), most of all due to the mud's caustic nature that could pose a risk for all living organisms (Brunori et al. 2005). In recent years, research has been carried out to increase reused or recycled red mud (Samal et al. 2013; Browner 1995; Ordonez et al. 2001; Parek and Goldberger 1976; Wagh and Douse 1991; Sglavo et al. 2000; Yalcin and Sevinc 2000) or to reduce red mud tailings (Li 2000)

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and to improve the methods of disposal (Rout et al. 2013). Finally, attempts are being made to tackle the problem by reducing the generation of red mud at the source through suitable beneficiation of the starting bauxite material (Liu et al. 2011). However, as it was concluded by Samal et al. (Samal et al. 2013) because of the environmental and safety concerns, customers do not want to accept products made using waste material. It is also the case in Poland, where red mud had been stored in quarry in Trzebinia (Małopolska province) in 1960–1984. Infiltration of the dump by rainwater and groundwater resulted in the formation of a deep reservoir of highly alkaline leachate Górka called "ecological bomb". Due to legal (ownership) and economic (cost) problems it has not been reclaimed for over 30 year (the company which managed the waste went bankrupt) creating the risk of disaster, which could have similar consequences to the Hungarian one. In recent years, with the support of national and EU funds the optimal solution for its reclamation has been proposed and will be realized.

The presented case study covers environmental analysis in the case of "Górka". The chemical composition of the red mud waste in Górka may pose a potential threat to the environment due to leaching toxic substances (including heavy metals) from the waste, which may contribute to the contamination of the soil in the area of the reservoir. In addition, the contaminated leachate reservoir may enter the nearby lake Balaton and pose a threat to the health and life of humans. The aims of the study was to identify the impact of red mud on:

- leachates in Górka reservoir,
- soil around Górka reservoir,
- water and sludge bottom in Balaton lake.

1. Material and methods

1.1. Study Area

The article presents an abandoned red mud waste disposal site, known as Górka. It is located within the bounds of the industrial town of Trzebinia (Fig. 1), in the western part of Małopolska province, in the district of Chrzanów, Poland.

Between 1960 and 1984 part of the limestone and marl quarry (4.7 ha) was used to deposit approx. 600 thousand m^3 of red mud derived from the production of aluminium oxide refined using the Bayer process at the Refractory Raw Materials Factory. According to the current regulations Catalogue of waste (Journal of Laws of the Republic of Poland 2001, no. 112, Item. 1206) red mud waste located in Górka can be classified as:

- 01 03 09 – red mud from alumina production other than those mentioned in 01 03 07;
- 01 03 07* – other wastes containing dangerous substances from physical and chemical processing of metals;
- 10 12 wastes from manufacture of ceramic building products, steel and refractory (ceramic goods, bricks, tiles and construction products);

Fig. 1. Location of the research site

Rys. 1. Lokalizacja obszaru badań

Fig. 2. View of the Górka and Balaton reservoirs in satellite map

Rys. 2. Widok zbiornika Górka i Balaton na mapie satelitarnej

- 10 13 wastes from mineral binders (including cement, lime, plaster), and the products made therefrom;
- 17 01 waste materials and construction elements and road infrastructure (such as concrete, bricks, tiles and ceramics).

The waste material unprotected against infiltration by rainwater and groundwater over time created a reservoir of leachate with an area close to 3 ha called Górka. It also turned out that other types of waste including tyres, construction waste, scrap metal etc. were illegally dumped in the reservoir.

The discharge of leachates from the reservoir is done via a shaft into a water stream which is found below it, namely the Ropka (stream flowing out of the Balaton reservoir). The Balaton reservoir was created in the mid-1970s as a direct result of the flooding of a closed-down quarry, and has become a local recreational attraction thanks to the excellent water quality, the depth of the reservoir which makes recreational diving possible as well as the valours of the surrounding countryside. Górka and Balaton reservoirs are shown in Fig. 2 (satellite map) and in Fig. 3 (current).

The excess leachate from the landfill was initially discharged by gravity into an existing tunnel, which leads to the nearby Chrzanów wastewater treatment plant. In 1991, a discharge of leachate was stopped due to damage of the collector and the biological part of the treatment plant in Chrzanów. It need to be noticed, that in 2000 a substantial rise in the level of leachate in Górka reservoir caused by the clogging of a discharge mine shaft was observed. This has led to spillage out the leachate over the surrounding terrain, creating a health and safety risk for the local community and environmental. Meanwhile the fireproofing materials company, which had been the main land user, had gone out of business, leaving their unoccupied properties in a state of collapse, ultimately leading to the municipality of Trzebinia taking over the supervision of the area. The municipality also undertook repairs to the water basin in Górka to reduce the risk of spillage and leachate contamination in the surrounding area. The remedial actions were taken in order to a preventing an environmental catastrophe. This required pumping and neutralisation of the alkaline leachate and removal of the silt from the adit to drain leachate safely by gravity to a local stream. As a result of pumping out the leachate, their level went down by almost 12 m – Fig. 4.

Fig. 3. Górka (a) and Balaton (b) reservoirs (photos by E. Pietrzyk-Sokulska)

Rys. 3. Górka (a) i Balaton (b) (zdjęcia E. Pietrzyk-Sokulska)

Fig. 4. View of the Górka reservoir after pumping of leachate (photo by E. Pietrzyk-Sokulska)

Rys. 4. Widok zbiornika Górka po odpompowaniu odcieków (zdjęcie E. Pietrzyk-Sokulska)

Moreover, according to the legal limits, there is an limit of the number and quality of leachates pumped out – they cannot exceed a minimum of 700 m^3/day, with a pH 6.5–12.5, a temperature of 30°C, COD_{cr} at 150 mg/l, general suspended matter of 50.0 mg/l and a alkalinity of 3000 mg $CaCO_3$/l. Because the Górka reservoir is located above the Balaton lake, this creates a potential threat of leachate infiltration deep into the rock and may poses a potential changes in the water quality in the Balaton. Keeping in line with these mentioned requirements is essential for maintaining and preserving the quality of water in the Balaton reservoir. Currently, the reservoir Górka, after intensive pumping of leachate in recent years, consists of two ponds – one big and one small, separated by a waste dump which acts as a dam. They have a depth of 0.3–1 m, which is largely dependent on the intensity of rainfall and the inflow of water from the headwaters area, located to the eastern side of the reservoir. Currently, in the Górka reservoir is still accumulated leachate, which is monitored by the commune office, who as landowners are directly interested in maintaining the safety of the area.

1.1.1. Characteristic of red mud waste "Górka"

The analysis the composition of red mud waste Górka was conducted in previous years by other authors (Multivariate concept… 2010). This red mud waste dump is located on limestone and marles which are highly fissured and karsted. Red mud waste are insoluble residues composed of a mixture of silica (SiO_2), simple silicates and calcium silicates as well as calcium aluminosilicates (including unreacted sodium carbonate) and also aluminium and iron oxides. The red mud waste dump also ended up receiving construction waste, scrap metal, municipal waste (e.g. tyres, etc.), ashes and slag from local boiler stations and likely sediments from wastewater treatment facilities (high organic matter content). Granulometric analysis of waste samples in air-dry state revealed a predominance of sand fractions (from 46.5% to beyond 69.4% of their mass), gravel and fine rock particles (from 30.1% to 52.8% mass) and dust and clay particles (from 0.2% to 1.4%). Chemical analysis carried out on three test holes showed that they contain such compounds as Al_2O_3, Fe_2O_3 and Na_2O, CaO as well as K_2O and organic carbon (Albinus et al. 2004). The test results of content of trace elements were identified in the waste samples taken from various depths (16.7; 16.7; 17m) in the central part of the dump – Table 1. The concentrations of selected hazardous materials indicate the highest amount of Mo – max. 66.5 ppm, Cr_{total} – max. 160.6 ppm, Zn – 339.4 ppm, Pb – 311.5 ppm and As – max. 623.4 ppm; Ba – 331.2 ppm.

Table 1. The content of trace elements in the waste from the landfill in the Górka reservoir [ppm dry weight] in 2003

Tabela 1. Zawartość pierwiastków śladowych w odpadach ze składowiska w zbiorniku Górka [ppm w suchej masie] w 2003 r.

Element	Variation interval	Average content in test holes [depths]		
		16.7 m	16.7 m	17.0 m
Sr	73.5–334.6	226.0	245.7	125.0
Mo	0.6–76.0	66.5	52.8	25.2
Cr_{total}	62.3–260.7	160.6	126.3	90.3
Cr^{+6}	<0.03	<0.03	–	–
V	66.7–287.4	258.7	202.5	112.5
Ga	10.7–21.4	17.5	16.2	18.3
Ba	93.9–496.8	151.8	193.0	331.2
Zn	131.3–491.8	205.7	212.0	339.4
Cu	25.8–124.3	40.0	54.1	91.1
Pb	28.6–448.2	77.3	69.3	311.5
Li	22.2–97.5	59.7	67.2	47.5
Co	8.3–24.4	20.2	17.3	12.2
Cd	0.2–2.3	0.8	0.7	1.4
Hg	0.02–0.11	0.04	0.02	0.06
As	157.4–695.5	623.4	416.8	337.4

Source: Multivariate concept… 2010

Analysis of sediment from the bottom of the Górka reservoir was also conducted in previous years (Kowalski et al. 2005). It is established that the bottom of the Górka reservoir contains a layer of bottom sediments – sludge thickness of 20–30 cm. The results of the research of their chemical composition conducted in 2005 are presented in Table 2. The chemical composition of sludge indicates a high content of SiO_2 (28.6%) and CaO (25.9%), clay (6.2%), and sodium, magnesium, iron (> 0.5%). The concentration of trace elements were high for Mn (347 ppm), Cr_{total} (243.6 ppm), Ba (148.3 ppm), Zn (131.7 ppm), Sr (119.1 ppm) and As (76.7 ppm). The content of Cd, Cr^{+6} and Hg were below 0.5 ppm (Kowalski et al. 2005).

Table 2. Chemical composition of the sludge at the bottom of the Górka reservoir in 2005

Tabela 2. Skład chemiczny osadów z dna zbiornika Górka w 2005 r.

Chemical compounds	Content [%weight]	Trace elements	Content[ppm]
SiO_2	28.59	Sr	119.1
TiO_2	0.33	Mo	0.9
Fe_2O_3	1.47	Cr_{total}	243.6
Al_2O_3	6.26	V	42.5
CaO	25.86	Mn	347.0
MgO	1.43	Ga	17.7
K_2O	2.63	Ba	148.3
Na_2O	1.58	Zn	131.7
MnO	0.04	Cu	22.7
SO_2	0.48	Pb	29.3
P_2O_5	0.17	Li	27.2
Cl	0.068	Co	7.5
TOC	0.28	Cd	0.5
LOI at 950°C	27.7	Cr^{+6}	<0.03
		Hg	0.03
		As	76.7

Source: Kowalski et al. 2005

In the sludge samples, microbiological tests were also conducted – there was no presence of mesophilic and psychrophilic bacteria and molds. It has been observed a small amount of denitrifying and sulfate-reducing bacteria and species *Thiobacillus denitrificans*. This microorganisms are widely distributed in the environment but they are safe for living organisms (Multivariate concept… 2010).

The chemical composition of the red mud waste in Górka may pose a potential threat to the environment due to leaching toxic substances (including heavy metals) from the waste, which may contribute to the contamination of the soil in the area of the reservoir. In addition, the contaminated leachate reservoir may enter the nearby lake Balaton and pose a threat to the health and life of humans. Therefore, it should be identified the impact of red mud on leachates in Górka reservoir, soil around this reservoir, water and sludge bottom in Balaton lake.

1.2. Experimental procedure

The investigations were carried out in the samples taken from the Górka:
- leachates from the reservoir;
- soil around the reservoir

and in the samples taken from the Balaton lake:
- water from the reservoir;
- sludge bottom from the reservoir.

In order to determine some physicochemical indicators, generally accepted methodologies (Dojlido et al. 1999) were used:
- pH in H_2O and KCl – potentiometric method (PN-ISO 10390:1997);
- heavy metals – inductively coupled plasma atomic emission spectrometry method, ISP-AES apparatus (PN-EN ISO 17294-1:2007, PN-EN ISO 17294-2:2006);
- selected elements and ions – (PN-EN ISO 11885-1:2009, PN-EN ISO 17294-1:2007);
- alkalinity, chloride ion – titration method;
- redox potential (Eh) – electrochemical method.

Inorganic components were measured at an accredited laboratory (PCA-AB 1050).

2. Results

2.1. Górka reservoir

A chemical analysis of the leachates from Górka reservoir was performed in the spring. The results of the testes are shown in Table 3. The samples were taken at a distance of 0.2, 0.4 and 0.5 m to surface. The results showed that leachates have high pH values (12.04–12.59) and high alkalinity (148.2–875.0 mg/l) and they exceed the limit values (Journal of Laws of the Republic of Poland 2014, Item. 1482). The redox potential is variable at different distances from the surface (–3 mV–33 mV). In the leachate exceeding the permitted standards for selected elements were observed. Limit values for chloride is < 300 mg/l, sulfates < 250 mg/l, 0.05 mg/l for chrome, 0.01 mg/dm^3 for copper, 0.4 mg/l for aluminum, 0.04 mg/l for molybdenum and 0.31 mg/l for phosphates (Journal of Laws of the Republic of Poland 2014, Item. 1482). The leachate represents a risk

Table 3. Results of chemical analysis of leachates from the Górka reservoir

Tabela 3. Wyniki analizy chemicznej odcieków ze zbiornika Górka

Indicator	Unit	Sample [near to surface, m]		
		I [0.2]	II [0.4]	III [0.5]
pH	–	12.04	12.59	12.09
Eh	mV	–3	21	33
Alkalinity	mg/l	148.2	875.0	359.5
As	mg/l	0.462	0.345	0.339
Cl	mg/l	340.3	237.5	202.1
Al	mg/l	36.32	38.4	38.17
Cd	mg/l	0.0003	<0.0003	0.0003
Co	mg/l	0.002	0.0009	0.0018
Cr	mg/l	0.152	0.091	0.121
Cu	mg/l	0.092	0.097	0.105
Mn	mg/l	0.035	0.009	0.033
Mo	mg/l	0.0799	0.058	0.0723
Pb	mg/l	0.0092	0.0011	0.0087
Ca	mg/l	4.09	6.36	7.08
Mg	mg/l	1.0	0.45	1.07
Na	mg/l	2 044	2 124	1 907
K	mg/l	48.1	50.27	45.98
Zn	mg/l	0.025	<0.01	0.024
SO_4	mg/l	446.1	485.3	441.6
PO_4	mg/l	1.46	0.87	1.29
CO_3	mg/l	2 060	1 138	1 772
SiO_2	mg/l	140.1	89.2	134.8

Source: Pietrzyk-Sokulska and Kulczycka 2013

to the surrounding environment (groundwater and soils) e.g. on account of its high alkalinity.

Soil samples were taken from around the Górka reservoir to assess the level of their contamination. The objective was to clarify the impact of red mud leachate on the soils around the reservoir. It was determined that the soil layer on the bank on Górka reservoir contains primarily highly anthropogenically processed industrial waste with an initial layer of humus (0–10 cm). The waste material features an unnatural layering of soil matter and the absence of soil strata formed as a result of natural pedogenic processes. The soils are extremely calcareous, contain stone and gravel fractions in the amount of 50–70%. According to the prevailing classification of soils (Classification Polish Soils 1989), they can be attributed to anthropogenic soils with an poorly developed soil profile. Three representative samples of soils a depth of 0–15 cm located on the bank on Górka reservoir were studied to define the total content of heavy metals (Mn, Cd, Cr, Al, As) and pH. The results are show in Table 4.

Table 4. Content of contaminants in soil surrounding the Górka reservoir

Tabela 4. Zawartość zanieczyszczeń w glebie wokół zbiornika Górka

Nr	Sample location	pH		Mn	Cd	Cr	As	Al
		H_2O	KCl	[mg/kg dry mass]				
1.	Reservoir bank	8.3	7.3	308.63	0.325	13.10	3.97	20 238.35
2.	Reservoir bank	9.5	8.1	347.13	1.525	10.85	4.22	12 757.10
3.	Quarry bank	7.7	7.2	449.13	3.325	37.45	6.28	20 563.35
4.	Quarry bank	7.7	7.1	626.13	1.925	26.45	4.65	26 119.60
5.	Quarry bank	7.5	7.1	326.63	1.700	15.23	4.47	15 669.60
6.	Quarry bank	7.4	7.1	338.91	1.950	12.37	4.50	13 479.93

Source: Pietrzyk-Sokulska and Kulczycka 2013

According to Polish standards of soil quality, the area under analysis can be classified as industrial brownfield areas, and communication areas. There were no significant differences in the concentrations of metals in the reservoir rim and quarry rim. The concentration of aluminim was the highest in quarry rim and it was equal to 26119.6 mg/kg DM. The concentration of manganese was also high ant it was in the 308.6–626.13 mg/kg DM range. The maximum allowable limits for cadmium was exceeded (Journal of Laws of the Republic of Poland 2002, no. 165, Item. 1359). As regards pedodiversity, the heavy metal contamination clearly influenced quality and function of soil (Vacca et al. 2012).

2.2. Balaton lake

The results of chemical tests were carried out for water quality in Balaton lake for horizons I, II and III at different depth levels (2.5 m; 5.0 m; 7.5 m, reservoir bottom). This analysis was undertaken because of a lack of any previous chemical tests of the water in all horizons. The results of the tests are provided in Table 5. They indicate that the pH of the water of Balaton is stable across the entire spectrum and has a value range of 8.20 to 8.28 (moderately alkaline) whilst the chemical composition of the water in compliance

Table 5. Results of chemical analysis of water from the Balaton reservoir

Tabela 5. Wyniki analiz chemicznych wody ze zbiornika Balaton

Para-meters	Units	Results											
		Horizon I – depth [m]				Horizon II – depth [m]				Horizon III – depth [m]			
		2.5	5.0	7.5	bottom	2.5	5.0	7.5	bottom	2.5	5.0	7.5	bottom
pH	–	8.24	8.21	8.27	8.20	8.26	8.20	8.26	8.22	8.28	8.23	8.28	8.24
Eh	mV	256	250	245	245	244	245	245	244	233	238	243	240
Alkalinity	mg/l	203.6	211.9	228.6	238.5	185.3	215.3	236.9	255.2	204.5	227.7	249.3	242.7
Cl	mg/l	25.3	24.9	25.6	26.4	26.1	23.3	28.1	25.9	24.6	26.9	23.3	25.9
Al	mg/l	0.014	0.011	0.01	0.03	0.013	0.01	0.008	0.01	0.010	0.008	0.007	0.01
Ca	mg/l	72.60	78.79	81.7	83.8	73.91	78.0	84.71	91.8	75.36	77.94	83.57	88.6
Mg	mg/l	14.48	14.95	15.1	14.9	14.73	14.8	15.97	16.9	15.37	15.12	16.04	16.4
Na	mg/l	20.97	20.99	20.2	20.4	19.55	19.8	21.30	22.6	20.62	20.85	21.49	22.4
K	mg/l	3.90	3.90	3.86	3.98	3.81	3.75	4.11	4.47	4.00	3.92	4.16	4.22
Zn	mg/l	<0.01	<0.01	0.02	0.04	<0.01	0.01	0.015	0.03	<0.01	<0.01	0.00	0.03
SO_4	mg/l	75.50	80.10	78.8	77.0	77.50	78.4	78.10	76.0	84.20	74.30	77.60	79.6
PO_4	mg/l	0.03	0.01	0.03	0.05	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
SiO_2	mg/l	0.80	1.40	1.70	1.80	0.90	1.40	1.60	1.60	0.70	1.20	1.60	1.90

Source: Pietrzyk-Sokulska and Kulczycka 2013

with existing law puts it in the highest class of water quality (Journal of Laws of the Republic of Poland 2014, Item. 1482). The only other observation of note concerns the slight rise with greater depth in the content of calcium, chlorides and silica which may be attributed to the weathering of rock (limestone and marl) in the bedding.

During the water quality tests in the Balaton reservoir, samples of sediment – sludge bottom were taken from the reservoir to assess their chemical composition – Table 6.

The above results show that the silt from the bottom of the Balaton reservoir is characterized by the accumulation of a large quantity of contaminants, including heavy metals. The current chemical composition in the bottom sediment include aluminosilicates, sulphates etc. and contaminants as well as artificial fertilisers washed out of the surrounding area (potassium and phosphorus). The presence of lead, zinc, iron and cadmium may be attributable to the washing out of these particles from mineralized rock formations of the Triassic period.

Table 6. Results of chemical analysis of silt samples from the bottom of the Balaton reservoir

Tabela 6. Wyniki analizy chemicznej próbek mułu z dna zbiornika Balaton

Parameter	Unit	Results		
		Horizon I	Horizon II	Horizon III
Ca	mg/kg	332 383	302 701	237 552
SiO_2	mg/kg	184 000	121 000	261 000
Al	mg/kg	15 135	16 788	13 764
S	mg/kg	12 621	18 527	20 414
Fe	mg/kg	11 793	12 390	12 131
Mg	mg/kg	3 665	4 116	3 157
K	mg/kg	1 789	2 246	1 582
Zn	mg/kg	1208	1604	1 365
P	mg/kg	1070	1115	922
Na	mg/kg	421	548	335
Mn	mg/kg	225.9	250.9	213.4
Pb	mg/kg	123.4	162.6	147.5
Cu	mg/kg	45.52	56.39	41.62
Cr	mg/kg	18.00	27.66	17.83
As	mg/kg	16.35	7.24	12.19
Cd	mg/kg	4.97	8.16	7.13
Co	mg/kg	4.66	5.83	5.47

Source: Pietrzyk-Sokulska and Kulczycka 2013

3. Discussion

3.1. Impact of Górka reservoir on the water

The chemical tests of the leachate from the Górka reservoir conducted in 1997 revealed high alkalinity. The volume of pH was in the 10.93– 13.4 range (Czop et al. 2002; Albinus et al. 2004). The next analysis, which were conducted in 2000 and 2003 (Czop et al. 2011) and in 2007 by local authority confirmed that the value of pH was greater than 13. Moreover, high mineralization (1600 mg/l) and exceeding of concentration limits of many indicators had been observed. The analysis confirmed that there is a trend of increasing concentration of pollutants and pH values with depth, mainly due to in-gassing of atmospheric CO_2 into the surface layer and due to density stratification in the water column (Czop et al. 2011).

In this study (conducted in 2012) the samples were taken nearer surface than in previous publications. Even that, the results showed much lower concentration of elements than earlier analyses, but it still remained at a level too high with respect to acceptable values. It can be presumed that in the 5 years which separate the two analyses, the lowering of the concentration in the leachate is connected with the lessening of the rate at which rain and groundwater infiltrating through the heap wash away the contaminants, although it may also be that it is due to the earlier washout of the majority of environmentally harmful contaminants. Whatever the case may be, leachate still represents a risk to the surrounding environment (groundwater and soils). This is confirmed by the damage of plants by alkaline leachate, which was observed in 2006 – Fig. 5.

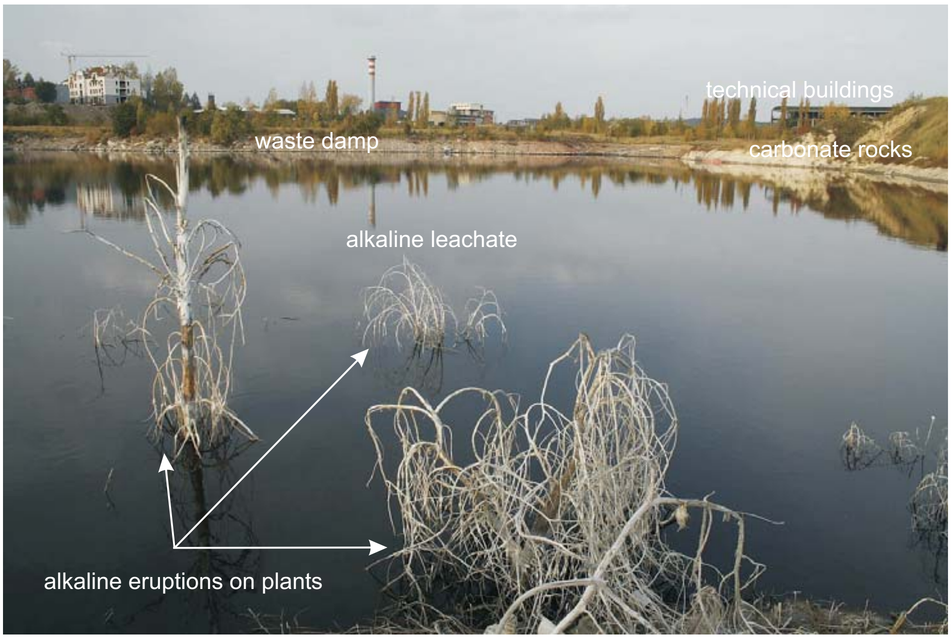

Fig. 5. Plants damaged by alkaline leachate (2006, photo by E. Pietrzyk-Sokulska)

Rys. 5. Uszkodzona przez alkaliczne odcieki roślinność (2006, zdjęcie E. Pietrzyk-Sokulska)

Due to the high contamination, leachate should be treated before being discharged to the receiver. Sediment from the bottom should be collected and transported to the landfill for hazardous waste. These treatments should be done before the rehabilitation of bottom of the reservoir. Moreover, the water source area should be insulated from the ground – no contact with the landfill.

Using the same method a series of chemical tests were carried out for water quality in Balaton lake for three horizons. This analysis was never undertaken before for this lake.

The results showed that water has a slightly alkaline pH (pH 8) – Table 5. The chemical composition of the water in compliance with existing law puts it in the highest class of water quality. It was necessary to the execution of tests of bottom sediments in the lake – Table 6. There were no prior studies about bottom sludge in Balaton lake, so in the present one it is difficult to definitively say whether there are more or less contaminants and if the infiltration from the Górka reservoir upstream has any connection with it. In the water the contaminants were not recorded at such a level and thus they do not pose a risk to bathers. Their source most likely are small quantities of waste accumulated at the bottom of the inactive mine excavation (prior to it being filled up with water). However, over the 40+ years of the Balaton reservoir's existence this waste was washed out and accumulated in the silt. It is possible that a portion of the waste released into the water did not dilute and was not drained away in the waters flowing out of the reservoir (the Ropka stream), although this cannot as yet be substantiated given that no such tests were conducted since the waste heap was formed.

It can be concluded that presence of red mud landfill in the near distance does not significantly affect the quality of water in Balaton lake. The infiltration of contaminants from the Górka reservoir through fissured and karsted rock mass into the Balaton reservoir is not taking place. Due to this facts, the use of reservoir for a recreational purposes is safe for the environment and living organisms. However, it does not however signify that there is no threat of that occurring, so the water quality in the lake should be monitored.

3.2. Impact of Górka reservoir on the soil

In 2012, soil samples were taken from around the Górka reservoir to assess the level of their contamination. The objective was to clarify the impact of red mud waste and leachate on the soils. According to current regulations (Journal of Laws of the Republic of Poland 2002, no. 165, Item. 1359), the area around the Górka reservoir is classified as "C" – industrial areas. According to the current specifications, the area around the reservoir Górka is considered to be not contaminated with cadmium, chromium, arsenic, aluminum and manganese. It was determined that the soil layer on the bank on Górka reservoir contains primarily highly anthropogenically processed industrial waste with an initial layer of humus. The presence of Al and Mn in the analysed soil samples is connected with the production at an earlier time of refractory materials in the area as well as with the red mud waste deposited inside the quarry. Rainwater and groundwater infiltrating into the interior part of the waste heap washed the contaminants out of the waste, thereby generating dangerous leachates which in turn saturated the surrounding area. A relatively high content of Al in the soil does not necessarily signify its phytotoxicity. One of the factors influencing in what form these elements are present in the soil and made available to plants is the soil pH (Kabata-Pendias and Pendias 1999). As it turns out, greater acidity decreases the solubility of most elements and their concentration in soils is consequently lower. To lower the take-up of metals by plants it is necessary to maintain them between basic and slightly alkaline (Mercik and Kubik 1995).

This would appear to be confirmed by the presence of grassy vegetation in the area in question (e.g. *Colonial Bentgrass*, *Creeping Bentgrass*), in some locations alongside clumps of bushes and single trees. The trees growing here include silver birch (*Betula pendula*), which is considered a species with little requirements as far as soil quality, moisture content are concerned, and which grows in sunny areas. More common bush species include Common Dogwood (*Cornus sanquinea*), Common Hazel (*Corylus avellana*), White Poplar (Populus alba) and on the rims of the old excavation site different species of willow, including Pussy Willow (*Salix caprea*) and Gray Willow (*Salix cinerea*). This vegetation is the result of natural succession, the migration phase. An invasive species – Medick Broomrape (*Orobanche lutea Baumg*) – was found to be growing on the southern rim of the area. This species because it occurs rarely in Poland is subject to species protection.

3.3. Social responsibility in the case of Górka

The presence of red mud waste Górka has not only to the environmental impact of the soil and water. The problem of waste management leads to a number of social and financial responsibility. Improving the quality of leachate in Górka reservoir, and to maintain good water quality in the Balaton lake requires a comprehensive approach that will allow safe use by the inhabitants of Trzebinia and visitors. Current EU regulations do not allow for such a scenario to take place as has happened in the case of the Górka waste dump, and so this case can serve as a warning of the consequences of such actions. The municipality of Trzebinia should take comprehensive measures like:

- land reclamation of industrial waste "red mud" Górka,
- eliminate hazards at aquatic in Górka reservoir – drained alkaline leachate, protection of headwaters,
- provide funding for safety work,
- improve environmental quality standards,
- increase attractiveness of the site,
- adaptation of water bodies surrounding recreational areas,
- provide access to the nearby residents,
- creation of public-private partnership (PPP) for the use of brownfield sites,
- increase the competitiveness of the municipality.

The implementation of this actions will ultimately: improve the image of the municipality (liquidation of remaining brownfields, recovery areas for redevelopment, the protection of areas of high natural value against buildings and industrialization, increase quality of life for residents); eliminate the possibility of an environmental disaster (especially surface water and soil) (Pietrzyk-Sokulska and Kulczycka 2013).

The degraded site will thanks to the support of national and EU funds recover its natural valor's and utility value and will become an attractive area for future investors without affecting the environment and human health.

Conclusions

The issues surrounding industrial waste dumps abandoned many years ago which were not managed at the appropriate time is complex. This is due not only to the environmental impact of the waste itself, but also to the leachates which are created as a result of rainwater and groundwater washing through the waste mass. The results of the analysis and tests carried out on the abandoned red mud waste heap reveal that:

1. The red mud dumps must be always isolated, as it pose a serious potential hazards that can affect the health and lives of the local community.
2. Acceptable limits for concentrations of dangerous compounds in the water and soil environment are not exceeded (data are available only from last 10 years) despite 30 years having past since waste stopped being deposited at the site Górka and no reclamation work having been carried out.
3. Relatively good soil quality in the area surrounding the waste dump Górka does not constitute a barrier to future biological reclamation which would bring back the natural valour's which are the basis for recreating the original ecosystems found here.
4. This study highlights that the decision process to find the best solution for reclamation of post-industrial waste depends on complex and detailed analyses of water, leachate and soil, which should be conducted during planning process.
5. This study also highlights that non-selective disposal of red mud disposal creates additional environmental and economic problem. In this case, it can be concluded that presence of red mud landfill Górka in the near distance does not significantly affect the quality of water in Balaton lake. But in case of uncontrolled leakage of leachate, it could lead to environmental disaster in study area, so hedging activities are necessary.

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WPŁYW SKŁADOWANIA ODPADÓW TYPU *RED MUD* NA ŚRODOWISKO LOKALNE NA PRZYKŁADZIE „GÓRKI"

Słowa kluczowe

zagrożenia środowiskowe, odpady przemysłowe, *red mud*, odcieki zasadowe, składowanie, obszary poprzemysłowe

Streszczenie

Pomimo zaostrzenia wymagań środowiskowych, na terenie Europy nadal występują zdegradowane obszary przemysłowe, które stanowią poważane zagrożenie dla środowiska i zdrowia ludzi. Jednym z nich są składowiska odpadów typu *red mud* o silnie alkalicznym odczynie, często zawierające toksyczne związki. Na całym świecie jest zmagazynowanych około 2,7 mld Mg odpadów typu *red mud*. W artykule przedstawiono problemy związane ze składowiskiem odpadów tego typu, zlokalizowanym w opuszczonym kamieniołomie pomarglowym w Trzebini (Polska południowa). Identyfikacja zachodzących w nim zmian w ostatnich latach oraz związanego z nimi wpływu na środowisko pozwoliła wskazać sposób postępowania minimalizujący istniejące zagrożenia. Przeprowadzone w trakcie 30-letniego istnienia wyrobiska badania wskazują, iż zachodząca w tym czasie infiltracja zgromadzonych na zwałowisku odpadów przez wody deszczowe i podziemne była powodem powstania głębokiego zbiornika silnie alkalicznych odcieków (pH >13), które mogą negatywnie oddziaływać na środowisko wodno-glebowe. W 2000 r. podniesienie poziomu odcieków w zbiorniku do krawędzi wyrobiska zagroziło ich przelaniem na otaczający teren, stwarzając zagrożenie dla zdrowia ludzi. Działania zaradcze, w postaci odpompowywania nadmiaru odcieków, zapobiegły czasowo ekologicznej katastrofie. Ze względu na to, że skład chemiczny odpadów *red mud* może stwarzać potencjalne zagrożenie dla środowiska ze względu na wypłukiwanie z nich substancji toksycznych, które mogą przyczynić się do skażenia gleby i wody wokół zbiornika, szczegółowe analizy odcieków ze zbiornika Górka, gleby wokół zbiornika Górka, wody i osadów dennych w jeziorze Balaton (znajdującego się w pobliżu składowiska) zostały przeanalizowane. Składowany odpad przestanie stanowić zagrożenie dopiero dzięki całkowitej utylizacji. Może to nastąpić w roku 2015 dzięki realizacji kompleksowych prac rekultywacyjnych dofinansowanych z funduszy rządowych i UE.

IMPACT OF LANDFILLING OF RED MUD WASTE ON LOCAL ENVIRONMENT – THE CASE OF GÓRKA

Keywords

environmental hazards, industrial waste, red mud, alkaline leachate, landfilling, post-industry area

Abstract

Despite stricter environmental regulations, degraded post-industrial areas continue to exist in Europe which pose a serious threat to the environment and health. An example of these high-risk areas are red mud dumps which are highly alkaline and often contain toxic elements. Worldwide approximately 2.7 billion tons of red mud have been stored. The present article describes the issues that have arisen in the case of an abandoned red mud dump located in Trzebinia (southern Poland). Identifying the changes taking place in the dump last years and the resulting effects on the environment made it possible to determine what action can be taken to minimize risks to the environment. During the 30-year existence of the excavation, studies on the infiltration of the dump by rainwater and groundwater were carried. In this period of time the infiltration resulted in the formation of a deep reservoir of highly alkaline leachate ($pH > 13$), which may have a negative impact on the water and soil environment. In 2000, the raising the level of leachate in the tank threatened to spill out into the surrounding area and pose a risk for human health. The response to this threat – the pumping of excess of leachate, prevented an environmental catastrophe. Due to the fact that the chemical composition of the red mud waste could pose a potential threat to the environment due to leaching toxic substances from the waste, which may contribute to the contamination of the soil and water around the reservoir, analysis leachates in Górka reservoir, soil around Górka reservoir, water and sludge bottom in Balaton lake (located near landfill) were presented. Red mud remains a problem which can only be solved if the waste pile undergoes proper treatment. It could take place in the 2015 thanks to reclamation efforts part-financed by national and EU funding.