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Landfill runoff water and landfill leachate discharge and treatment

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Abstract

The continuously increasing requirements for environmental protection create problems for many countries in treating landfill runoff water. In the present paper, the creation, chemical composition and treatment possibilities for leachate in 5 Estonian landfills are studied. Generally, the younger the landfill, the higher concentrations of pollutants. In the Väätsa landfill, the landfill runoff water flow rate has been measured up to 150 m^3/d, average flow ($Q_{average}$) = 10–20 m^3/d. The composition of pollutants in the leachate depends on the character of the deposited waste material and on the age of the landfill. In Väätsa landfill, the leachate biochemical oxygen demand (BOD_7) is in the limits of 300–960 mgO_2/l, in Uikala landfill the leachate BOD_7 is in the limits of 231–1750 mgO_2/l, but in Tallinn landfill it can reach up to 5500 mgO_2/l, chemical oxygen demand (COD) is 580–2390 mgO/l and 9100 mgO/l correspondingly. Ammonia nitrogen in Väätsa is between 50–330 mgN/l, in Uikala it is between 427–729 mgN/l, but it can reach up to 970 mgN/l in Tallinn. Total nitrogen (N_{tot}) in Väätsa is 130–470 mgN/l and 1335 mgN/l correspondingly, and in Uikala 564–1567 mgN/l. The content of heavy metals is relatively low, caused by the high content of sulphates (500 – 700 mg/l), causing rapid sedimentation of heavy metals from the leachate. In the older landfills, the efficiency of nanofiltration (NF) and reverse osmosis (RO) were investigated, and the rather good results were obtained for BOD_7 and COD. After RO treatment, the results were as follows: COD of 57 mgO/l, BOD_7 of 35 mgO_2/l. RO was able to reduce COD and BOD_7 of biologically treated leachate by 97.9% and 93.2%. NF reduced 98 and 41% of leachate COD and BOD_7. Neither RO nor NF was able to reduce the total nitrogen to the required discharge limit of 15 mg/l.

Keywords: landfill, landfill runoff water, landfill leachate, leachate characteristics, leachate treatment.

Concepts: Landfill runoff water – liquid from a landfill or waste site containing dissolved and toxic materials; Landfill leachate – any liquid percolating through the deposited waste and emitted from or contained within a landfill.

1. Introduction

More than 500,000 tons of municipal solid waste (MSW) are being disposed annually at the five new landfills in Estonia – Väätsa, Uikala, Torma, Paikre and Tallinn. The effective management of landfill runoff water and leachate, as a by-product of landfills, is one of the major challenges in meeting strict EU discharge standards [1]. Väätsa landfill runoff water including leachate is treated by reverse osmosis (RO) after biological treatment and stabilisation pond, Uikala landfill runoff water is treated by RO after stabilisation pond, Torma landfill leachate is treated by activated sludge treatment (AS) after stabilisation pond and is directly discharged into the nearest small-scale rivers. Due to small flow rate and insufficient dilution, the discharged landfill runoff water may impose a significant impact on the water quality if the discharge standards were not met [2]. The quantity and pollutant content of landfill runoff water depends on the characteristics of the site, the climatic and meteorological conditions of the site and composting sites on the density of wastewater systems, and on the physical characteristics of the waste.

Estonia lies in the northern part of the temperate climate zone, in the transition zone between maritime and continental climate, which is heavily influenced by the North Atlantic Stream, Baltic Sea, and geographical location of the country [3].

The flow rate of landfill runoff water in Estonian landfills is directly related to the intensity of rainfall and melting of snow. The diurnal, weekly and annual variations of the flow rates of landfill runoff water and leachate have large variations.

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The long-term average annual rainfall for all of Estonia is 750 mm. Rainfall variability by territory or temporally may be considerable. Figure 1 shows that the well-annual rainfall distribution has undergone major changes, particularly in the last analysed period [4].

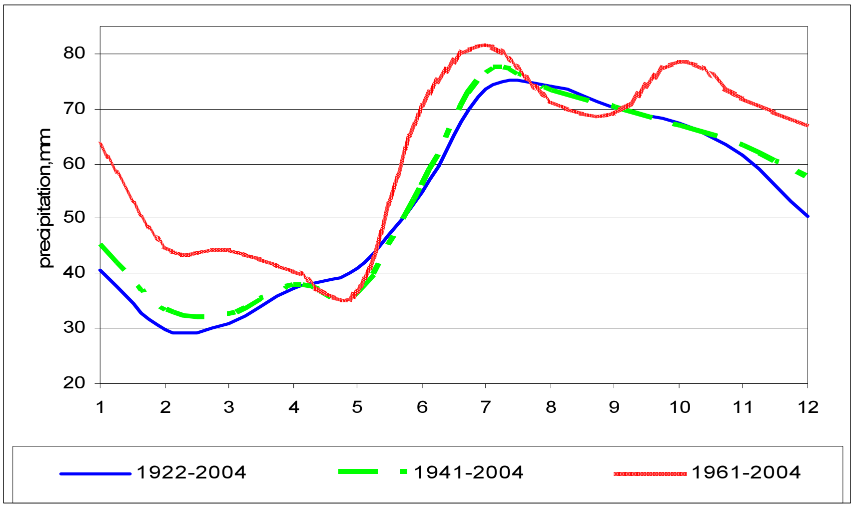

Fig. 1. Precipitation variability by Pärnu Meteorological station data [4]

2. Results and Discussion

Studies show that the quantity of some components of water from landfill (leachate, water from loading and collection sites, compost fields water, equipment and container's wash- and disinfection water) depending on the climatic and meteorological conditions of the site, but also on the activities in the landfill could be in the short term as well as long-term zero or negligible.

Municipal wastewater flow depends on the number of workers. However, landfill water and leachate flows are at high flow rates in the periods of spring and autumn rainfall and in the period when the snows melt. Some rainfall is absorbed in to the landfill sites, while more evaporates, with the intensity of the evaporation depending on temperature and rainfall. A mere 1-2 mm of rainfall evaporates completely in most cases. The impact of the leachate amount and duration of the discharge is directly dependent on the age of the dumps and the dump density. The flow is achieved approximately 3-5 hours after the start of the period of the rain or melt, depending on the obesity increase of the intensive dumps. High flow rate duration is also directly related to the duration of rainfall or the snow melt period. In case of a new deposition site and the compost field, before waste landfilling and the introduction of the material to be composted, approximately 90% of the stormwater is quickly collected from watertight underlain and discharged to sewer. Water is substantially pure and does not need to be treated. In accordance with the waste layer thickening, amount of landfill water begins to decline - some rainwater will retain a layer of waste and compost, and the share of evaporation increases. With waste layer obesity the leachate flow dynamics starts to stabilise. In new dump sites, storm water pass quickly through the waste and ends up in sewer taking along a large part of the easily washable pollutants. This evaporation is low. Research has shown that the quantity of leachate drained from old dumps is up to 20% of rainwater and from new dumps is on average 60% of rainwater. The older the landfill and the better compacted then the greater is the intensity of evaporation and the smaller is the amount of leachate. Stormwater residence time and amount of leached pollutants will increase. Landfill water as well leachate flow and dynamics are significantly affected by summer droughts and wintertime. A very large fluctuation is in the min, max as well as in average flow rates. For example, in Väätsa landfill different intensities of rain and snow melt period landfill water flow fluctuations were measured: Qmin = 0–2 m^3/d; Qmedium = 10–20 m^3/d (day 1.4 to 2.9 m^3/ha), Qmax = 50–95 m^3/d (7.1 to 13.6 m^3/ha), in some cases even up to 150 m^3/d (21.4 m^3/ha). Leachate flow fluctuations are smaller Qmin = 0–2 m^3/d; Qmedium = 5–15 m^3/s (0.97 to 2.92 m^3/ha), Qmax = 20–30 m^3/d (3.89–5.84 m^3/ha).

The refuse rate of degradation and the leachate content of pollutants are mostly dependent on the conditions within the landfill. An important factor is the moisture content of the waste. In dry environments, the decomposition of the waste and the methane gas released are substantially lower than in areas where the annual infiltration into waste is 50 to 100 cm [6]. It is widespread to send leachate or concentrate formed during the leachate treatment back to the landfill. At Väätsa and Uikala landfills, reverse osmosis concentrate is sent in the upper layers of landfill for this purpose. This increases the amount of leachate (for example, up to 10% in Väätsa and in Uikala up to 12%), and in that the concentration of pollutants. Through recirculation, the waste moisture content will usually increase from 15–20% to 40–50% [6]. In addition, this improves the spread of nutrients, substrate and bacteria with leachate recirculation.

At the stable methanogenic phase, the methane production rate will reach its maximum, and decrease thereafter, as a soluble substrate stock (carboxylic acids) decreases. In this phase, the methane production rate depends on the rate of hydrolysis of cellulose and hemicellulose. The pH continues to rise in the permanent status that comes when the concentration is only a few mg/l. In this phase, the BOD and COD ratio may fall below 0.1, because the carboxylic acids are consumed as soon as they occur [4]. The BOD_7/COD ratio significantly fluctuated quite according to studies in 2007 in landfill leachates: Väätsa 0.3–0.5; Tallinn 0.2–0.7; Uikala 0.2–0.6; Paikre 0.2–0.5. In 2010, the landfill leachate BOD_7/COD ratio was less than 0.1 in Väätsa [5].

Landfill water and leachate pollutant content is directly dependent on the rainfall intensity and the on-going activities on the territory of landfill: garbage sorting, technology of tipping and use of depositing site, etc. Research has shown that the highest concentrations of pollutants are in leachate and in the storm water collected from composting site. For example, the Väätsa landfill composting site sewage BOD_7 was 201–1875 mgO_2/l and in Tallinn landfill it was 850–2825 mgO_2/l. The leachate content of pollutant is strongly influenced by the composition of the waste deposited in the landfill and the processes in the body of landfill. As a result of physical, chemical and microbiological processes, pollutants from waste are transported to leachate. Estonian landfills contain mixed construction waste, mixed municipal and industrial waste; there are no significant quantities of chemical waste and landfill leachate can be characterised by the four types of pollutants in an aqueous solution: dissolved organic matter, inorganic macro components, xenobiotic heavy metals and organic compounds.

Garbage will go through at least four phases of decay in landfills: 1) the initial aerobic phase, 2) the acid phase of the anaerobic, 3) the initial methanogenic phase, and 4) the stabilising methanogenic phase. It is quite common that different decay phases are occurring simultaneously in different parts of the landfill. Moreover, each phase will affect the different composition of the leachate, leachate treatment technology selection and the changes taking place over time, depending on the degradation phase [7].

Väätsa landfill is 14 years old, Uikala landfill is 12 years old, Torma landfil is 13 years old, Tallinn landfill is 11 years old and Paikuse landfill is 8 years old. All of the landfills first disposal areas are in transition state from anaerobic acid phase to initial methaogenic phase. The new disposal sites of the landfills are in the initial aerobic phase. During the study period pollutant content of wastewater of different sources and treated landfill water of Estonia landfills was monitored. The landfill and leachate samples were analysed by the Environmental Research Centre laboratory and the hydrochemistry laboratory of the Institute of Environmental Engineering at Tallinn University of Technology. Dioxins were studied in Czech Republic.

Table 1 shows that in Uikala and Väätsa landfills, concentrations of pollutants have large variations in leachate and. landfill runoff water.

Table 1. Measured landfill runoff water and leachate average concentrations of pollutants in Väätsa and Uikala landfills 2007 [5].

Parameter	Unit	Väätsa landfill (medium)		Uikala landfill (medium)	
		Runoff water	Leachate	Runoff water	Leachate
pH		6.75	7.7	7.9	7.5
conductivity	µS/cm	5545	8090	14010	14553
SS	mg/l	650	400	411	298
BOD_7	mgO_2/l	1015	529	1196	697
COD	mgO/l	4859	1366	3855	2538
TOC	mgC/l	1313	375	1073	718
NH_4	mgN/l	94	198	562	592
N_{tot}	mgN/l	297	298	820	1072
P_{tot}	mgP/l	22	4.6	4.48	6.05
HCO_3	mg/l	2800	3805	6470	7260
SO_4	mg/l	290	588	401	172
Cl	mg/l	107	439	1593	1553
monobasic phenols	mg/l	235	49.1	2590	1510
dibasic phenols	mg/l	22.6	140	1878	1005
petroleum product	mg/l	14	29	<20	60
Fe^{2+}	mg/l	7.4	1.95	1.2	0.62
Fe^{3+}	mg/l	5.3	7.95	14.7	21.4
Hg	µg/l	0.05	0.148	<0.05	<0.05
Ag	mg/l	0.01	<0.01	<0.01	<0.01
Cd	mg/l	<0.02	<0.02	<0.02	<0.02
Cr	mg/l	0.032	0.187	0.286	0.260
Mg	mg/l	105	108	293	283
Mn	mg/l	10	0.273	0.367	0.557
Na	mg/l	57.5	675	1400	1425
Ni	mg/l	0.041	0.090	0.061	0.080
Pb	mg/l	<0.04	<0.04	<0.04	<0.04
Zn	mg/l	<0.1	<0.1	<0.01	<0.01
Cu	mg/l	0.040	0.094	<0.02	0.023

Landfill runoff water including leachate from the Väätsa landfill is treated by RO after biological treatment and stabilisation pond and Uikala landfill runoff water including leachate is treated by RO after stabilisation pond. Wastewater treatment plant efficiency indicators in the third and fourth quarters of 2013 are shown in Table 2.

Table 2. Content of wastewater discharged to the treatment plant and treated water effluent pollutant content of the wastewater treatment plants of Väätsa and Uikala landfills in 2013 [8], [9].

Parameter	Unit	Väätsa landfill			Uikala landfill		
		Inflow	III quarter	IV quarter	Inflow*	III quarter	IV quarter
pH		8.52**			7.5	6.7	6.6
SS	mg/l	260**	4	10	215		2.7
BOD_7	mgO_2/l	130	<3	<3	235	3	4
COD	mgO/l	3500	<14	<14	1370		
TOC	mgC/l	1500					
NH_4	mgN/l				790	8.3	1.5
N_{tot}	mgN/l	474**	3.6	1.5	820	8.3	3.7
P_{tot}	mgP/l	9.0**	0.03	0.09	5.8	0.017	0.022
SO_4	mg/l				490		5
Cl	mg/l	1500					
monobasic phenols	µg/l	15	7.3	<2	150	0.625	
dibasic phenols	µg/l	<10		<10	2200	2.2	
petroleum product	mg/l	0.02	<0.02	<0.02	0.08		

* inflow 2012 average data
** inflow data 14. 05. 2009

After six years of the successful operation of Väätsa landfill wastewater treatment plant from 2002 to 2008, the activated sludge (AS) treatment process was not working according to its design conditions. As the landfill ages, ammonia concentration increased significantly from 50 to 330 mgN/l. As a result, ammonia-nitrogen concentration could not be reduced to the required 15 mg/l without additional treatment. The toxicity of ammonia to microorganisms in the activated sludge tank also made the sedimentation tank unoperable, as designed. Consequently, the effluent is dark and contains high concentration solids. Since AS was not primarily designed to remove non-biodegradable organic chemicals, the removal of non-seeing as BOD_7/COD ratio dropped less than 0.18 in 2011, rendering the biological processes ineffective. To meet the discharge standards, membrane technologies such as reverse osmosis can be used either as a main step in a landfill leachate treatment chain or as a single post-treatment step. Membranes such as reverse osmosis (RO) and nanofiltration (NF) have pore sizes that are sufficient in retaining non-biodegradable organic pollutants and are very effective in the physical separation of a variety of large non-biodegradable compounds from water [10]. Therefore, the objectives of this study are to assess the treatment efficiency of RO and nanofiltration of the biologically treated leachate, so that the effluent qualities meet the discharge standards. In addition, the treatment efficiency by both RO and nanofiltration are also compared to select the best membrane for full scale implementation. In the present study, RO and NF were investigated to determine the treatment efficiency of biologically treated leachate at the Väätsa landfill [11].

The ineffectiveness of AS is confirmed by the percentage reduction of pollutants before the treated leachate was discharged into the receiving river from 2001 to 2012. The AS system completely lost its treatment efficiency because both BOD_7 and COD reduction decreased from more than 80% in 2003 to about 60% after the AS system in 2011. In 2012, the BOD_7 and COD reduction data reflected the new treatment with the RO disc tube type module as recommended by this study (Table 2).

During the research, it was decided in parallel to Väätsa landfill RO device testing to monitor the effectiveness of the full-scale RO treatment process in Uikala landfill. Polluted water from Uikala landfill territory, including leachate is collected into the equalising pond. From the equalising pond 4.5 to 5.0 m^3 of wastewater per hour is discharged to the wastewater RO container treatment plant with filter DT 29-09. Efficiency of RO is considered 99.6%. About 2–3 m^3/ h of treated wastewater is discharged into the recipient and the rest of the concentrate is pumped back into the landfill. Before the process of entering, the landfill runoff water is filtered in sand filter following cartridge filter. A sand filter captures particles greater than 50 µm and the cartridge filter separates suspended solids, which are ≥ 10 µm. If the loss of pressure in the sand filter is between 2-2.5 bar the filter will be washed with water-air mixture. If cartridge is clogged, then it is not regenerated; it is changed. Reverse osmosis will take place in a designated DT filter module, which is located in the disc-shaped membranes. The process is operated with a plunger pump, which is capable of operating at a pressure from 0.5 to 65 bar, the normal operating pressure is 60 bar.

A treatment plant works in difficult conditions, which can be seen in Tables 1 and 2. Characteristics of the efficiency of the wastewater treatment plant are in Table 3. In September 2009, in the RO equipment modules the disk membranes were replaced. There has not been an emergency, however, technical failures of individual nodes (e.g., pumps) has been reported.

Table 3. Pollution content in treated landfill runoff water at Uikala landfill wastewater treatment plant [5], [9].

Time	BOD_7 mgO_2/l	COD mgO/l	SS mg/l	N_{tot} mgN/l	P_{tot} mgP/l
21/02/2005	6	73	6	0.87	0.11
16/11/2005	2.1	40	2	2.8	0.054
09/01/2006	1.9	30	16	2.1	0.047
05/04/2006	11	75	12	2.8	0.088
12/09/2006	11	160	26	1.7	0.056
13/11/2006	11	90	6.0	4.8	0.029
15/01/2007	5.0	60	13	1.9	0.068
04/04/2007	17	130	9.0	0.71	0.04
08/10/2007	73	375	4	79	0.187
22/10/2007	13	30.6	5	16	0.029
2008	16.75	146.25	16	32.25	0.17
15/01/2009	<3	45	<2	6.4	0.024
07/04/2009	15	110	2	20	0.027
12/08/2009	3.6	40	2.7	25	0.015
30/11/2009	<3	36	6.6	3.9	0.012
2010	7.5	55.25	2.225	15.425	0.079
2011	2.25	26.25	1.1	4.375	0.04475
2012	3.0	30.0	2.0	5.8	0.02
II quarter 2013	6.7			8.9	0.02
III quarter 2013	3			8.3	0.017
IV quarter 2013	4		2.7	3,7	0,022

The Väätsa landfill Ultra-FLO pilot plant of low pressure reverse osmosis (LRO) was purchased from the Ultra-FLO Pte Ltd in Singapore. The Ultra-FLO pilot plant was operated in either RO or NF modes to test the treatment efficiency of either RO or NF. Nanofiltration testing spiral filtration uses NE 4040-90 membrane. Biologically treated landfill leachate passed through a cloth filter and two micro filter cartridge BB 5 mm. Finally, it passed through either a RO membrane or nanofiltration spiral wound NE 4040-90 membrane. Samples were taken from the permeate and the concentrate for analysis of different chemical parameters after a specific time of filtration [11].

Compared to reverse osmosis membranes, nanofiltration membranes have many advantages, such as lower operational pressure, high flux, high rejection of polyvalent ions, relatively low investment, and operational and maintenance costs [10], [12]. It is interesting to note that nanofiltration gave better results in terms of conductivity, N_{tot}, P_{tot} , and SS, while nanofiltration and RO were equally effective in removing BOD_7 and COD, which have a removal efficient greater than 95% [11].

During the fatigue test, RO reduced the COD and BOD_7 of biologically treated leachate by 97.9% and 93.2%, respectively, after 328 hours. However, only 39.0% and 21.7% reductions of P_{tot} and N_{tot} were achieved. After 586 hours, COD and BOD_7 reduction of the biologically treated leachate reduced slightly to 95.2% and 91.7%, respectively. After 328 hours of the nanofiltration process, there was a reduction in the biologically treated leachate for COD, BOD_7, P_{tot} and N_{tot} 97.5%, 93.8%, 99.2% and 68.6% respectively. During the test, fouling problems occurred and the spiral membranes needed to be washed, but finally were fully replaced [11].

3. Conclusions

At Väätsa landfill different intensities of rain and snow melt period landfill water flow fluctuations were measured: Qmin = 0-2 m^3/d; Qmedium = 10–20 m^3/d (day 1.4 to 2.9 m^3/ha), Qmax = 50–95 m^3/d (7.1 to 13.6 m^3/ha), in some cases even up to 150 m^3/d (21.4 m^3/ha). Leachate flow fluctuations are smaller Qmin = 0–2 m^3/d; Qmedium = 5–15 m^3/s (0.97 to 2.92 m^3/ha), Qmax = 20–30 m^3/d (3.89–5.84 m^3/ha).

When non-biodegradable organic and ammonia increased to critical level, the AS system will simply stop working. Even worse, the AS biomass may have decayed and release N_{tot} and COD into the treated leachate. To meet the discharge standards, reverse osmosis and nanofiltration were investigated in treating the biologically treated leachate. The reduction efficiencies of COD, BOD, dissolved inorganic as expressed as conductivity and suspended solids were all excellent after ineffective biological processes such as AS and biological lagoon. For example, the reverse osmosis process reduced COD or BOD_7 by 97% and 60%, respectively. Nanofiltration reduced 98%, 41%, and 68 % of biologically treated leachate COD, BOD_7, and N_{tot}, respectively. However, reverse osmosis was ineffective in removing N_{tot}. Nanofiltration has better results in removing P_{tot} and N_{tot} than RO. Although the COD, BOD_7, suspended solids, and P_{tot} can meet current legislation requirements, neither NF nor RO could bring the N_{tot} below the discharge limit of 15 mg/l. However, successful application of membrane filtration technologies require the efficient control of membrane fouling, especially when spiral membranes are used [11].

Based on the Tallinn University of Technology Environmental Engineering Institute previous research on wastewater formation and pollutant content evolution in Väätsa and Uikala landfills the Väätsa landfill wastewater collection and treatment system is designed and built in the years 2012/2013. The whole system consist from the landfill runoff water collection system, RO after biological treatment and stabilization in pond, as well pumping and distribution system for discharging concentrate from the RO back to the landfill. In the third and fourth quarters of 2013, the figures for the effluent were respectively: BOD_7 <3 mgO_2/l and <3 mgO_2/l, COD <14 mgO/l and <14 mgO/l, SS 4 mg/l and 10 mg/l, N_{tot} 3.6 mgN/l and 1.5 mgN/l, P_{tot} 0.03 mgP/l and 0.09 mgP/l, monobasic phenols 7.3 mg/l and <2 mg/l, dibasic phenols <10 mg/l (see Table 2). Treatment efficiency was in the fourth quarter by BOD_7 was97.7% and SS 96.2% and by COD, N_{tot} and P_{tot} treatment efficiency was more than 99%.

Uikala landfill sewage treatment plant works under difficult conditions, which is apparent in Tables 1 and 2. Treatment plant operational efficiencies are visible in Table 3. In September 2009, they replaced the RO equipment disk module membranes. There has not been an emergency. There have been technical failures of individual nodes (e.g., pumps). In 2011, the treatment efficiency was by BOD_7 was 98.5%, COD 97.1%, P_{tot} 98.8% and by SS and N_{tot} more than 99%. In 2013, in the fourth quarter, efficiency by BOD_7 was 98.3%, SS 98.7%, N_{tot} as well P_{tot} more than 99%.

The research showed:

- Very high concentrations of pollutants (and hence the pollution load) is collected from leachate and rainwater collected at the compost site;
- Leachate quantity and concentration of pollutants is directly dependent on rainfall intensity and dump obesity;
- Landfill leachates have a very high N_{tot} concentration and low concentration of P_{tot};
- Leachate contains high amounts of CODs (Uikala 1600 mg/l) and BOD_7;
- It is incorrect to use old car tyres dumps in the basecoat: iron concentration in leachate 6–8 mg/l, of iron corrodes 5–6 years and drainage blockages;
- Leachate contains very large amounts of phenols – in Uikala landfill leachate 3000–4000 mg/l;
- Leachate contain high amounts of magnesium and sodium. Uikkala landfill leachate at 300 and 1600 mg/l;
- The heavy metal content in landfill water does not exceed the limits.

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