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Original scientific paper

Comparison of Physical and Chemical Composition of Leachate from Three Municipal Waste Landfills: Sarajevo, Zenica and Tuzla (Bosnia and Herzegovina) Case Study

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ABSTRACT: In Bosnia and Herzegovina (BiH), waste management is still based on the preventive disposal of waste in landfills, of which most landfills are unregulated. According to World Bank reports, BiH must deal with the improvement of waste disposal to protect the environment. The aim of this study was to review the physical and chemical composition of leachate from municipal waste landfills. The following standard physicochemical methods were used: pH, total suspended solids (TSS), Biological Oxygen Demand (BOD5), Chemical Oxygen Demand (COD), Total nitrogen (TN), total phosphorus (TP), chlorides, and sulphates. The leachate quality test was conducted over three years at landfills in Sarajevo, Zenica and Tuzla, Bosnia and Herzegovina (BiH). Based on the processed data (from the processed tables), and in comparison with the expected values of pollutants in landfills over the period of 10 years, we can conclude the following: (1) Landfill "Smiljevići" Sarajevo, in the observed period of 3 years, has a higher average value than expected; (2) Landfill "Desetina" Tuzla, in the observed period of 3 years, has a higher average value than expected; (3) Landfill "Mošćanica" Zenica, in the observed period of 3 years, has a higher average value than expected.

Keywords: landfill, leachate, environmental, pollution.

INTRODUCTION

Leachate at the landfill is formed by filtering rainwater or other precipitation through the body of the landfill, during which soluble, colloidal, and suspended solids are separated from the waste (Robinson, 2005). The movement of water through the waste depends on the permeability, porosity, humidity, thickness, chemical migration and internal coatings of the waste, which form impermeable barriers and areas of accumulation in the waste. The amount of water collected layer by the time water saturation is reached indicates the ability of the waste to retain water. In this phase, moisture in the garbage begins to form leachate (Qasim, 1994).

One of the fundamental problems of waste management that landfills face in practice is the collection and treatment of leachate. Their composition and amount of production depend on many factors such as the age of the landfill, type of waste, climatic factors, etc. This wastewater must not be discharged directly into the environment without prior collection and treatment. The composition of leachate changes during the operation of a landfill. These changes mainly depend on the age of the landfill, the type and thickness of the deposited layer of waste, the shape and operation of the landfill and the interaction of leachate with the environment. The composition of leachate is particularly affected by the age of the landfill. As landfills age, the concentration of organic matter decreases more than the concentration of inorganic matter because they decompose and leach, while inorganic matter only leaks. Moisture significantly affects the degree of decomposition of waste, because it facilitates the exchange of substrate and nutrients, dilution of inhibitors and the growth of microorganisms. The way the landfill is built, the way it is disposed, as well as the climate have the most important influence on the moisture content of the landfill. Landfill leachate is a particularly

dangerous pollutant, which can be loaded with heavy metals and various organic and inorganic toxic substances such as pesticides, phenols, dioxins, etc. dissolved from waste. Therefore, these waters must be collected and treated in a controlled manner and their uncontrolled discharge into surface and groundwater without prior treatment must be prevented (Brkanac et al., 2013). In order to ensure long-term stable collection and continuous, economically viable leachate treatment, it is necessary to establish volume control (filtrate production) and a uniform leachate composition. With the strengthening of water quality protection measures and standards, the requirements for leachate treatment have increased significantly (Sang et al., 2006). According to the EU Landfill Directive 1999/31/EC, all water generated during landfill work should be collected and treated before any discharge to the final recipient. Recent research on leachate in municipal landfills shows that these waters are one of the most complex sources of pollution in nature, the composition and quantity of which change significantly during the life cycle of the landfill (Serdarević, 2007).

The production of the filtrate by the decomposition of municipal solid waste from non-hazardous waste landfills changes over time, as waste is decomposed through the following four phases of biodegradation (Toromanović et al., 2021, Qasim, 1994):

- I - The aerobic phase is the initial, short-term phase of decomposition that lasts about a month. At this stage, the decomposition of waste is performed by aerobic bacteria.
- II - The anaerobic, non-methane phase lasts approximately several months. Bacteria that do not need oxygen are active at this stage. The decomposition of waste mainly produces organic acids and alcohols. This phase represents the phase of hydrolysis and acidification.
- III - The anaerobic and unstable phase of methane will last from several months to a year. The chemical structure of the waste is stable; acetate and hydrogen are formed as products.
- IV - Anaerobic stable phase of methane lasts for several years. At this stage, methanogens are active and sensitive to pH. They exist only when the pH is around seven and mainly form CH_4 (methane) and CO_2 (carbon dioxide).
- V – It was additionally introduced as the final phase of waste decomposition. In this phase, some of the upper landfills may have aerobic zones.

Waste management in BiH is still at a low level and is based only on waste disposal in landfills, much of which are unregulated or illegal landfills. Very little research has been done on the impact of landfill water on human health and the environment. So far, a study of leachate management from the Sarajevo landfill has been conducted with a proposal for control and treatment (Serdarevic, 2017). A lot of work has been done on the research of leachate from the Banja Luka landfill (i.e. Markic, 2015), but there is still no significant research from the landfills of Zenica and Tuzla.

The subject of this paper is to monitor the physical and chemical composition of leachate from three landfills in BiH (Sarajevo, Zenica and Tuzla). These landfills are of different "ages", resulting in a different composition of leachate. Values of pollutants in landfills (Sarajevo, Zenica and Tuzla) of over ten years are used to show which results are best regarding the lowest number of parameters that are above the expected value of pollutants in these landfills.

MATERIALS AND METHODS

The subject of this paper is the analysis of leachate quality parameters from landfills in Sarajevo, Zenica and Tuzla in the period from 2016 to 2018.

The regional landfill "Smiljevići" Sarajevo started operating in the 60's of the last century and since 1998 it has been operating as a regional sanitary landfill. The total time of exploitation of this landfill is about 50 years. It covers an area of 65 ha. KJKP "Rad" collects and removes waste from the Sarajevo

Canton. Waste is disposed of at a sanitary landfill, approx. 4.5 km from the city zone. The daily amount of waste in the Sarajevo Canton is approx. 500 tons The selected membrane-biological (MBR) leachate treatment system (2006-2011) did not fully meet the set requirements for discharge treated leachate into a natural watercourse. During its trial operation, the MBR device achieved certain results, especially in certain parameters of leachate load, but from the beginning of the operation, shortcomings in the technical-technological solution were noticed. Due to mechanical failures, the device stopped working after several months of operation. Leachate, untreated and insufficiently purified, was discharged from the Sarajevo landfill into Lepenički potok.

The "Desetine" landfill in Tuzla started operating in 1990, i.e. the total period of waste disposal at this landfill is about 30 years. The sanitary landfill of the city of Tuzla "Desetine" is located in the north-western part of the city. The landfill occupies a total area of approx. 180,000 m^2. "Desetine" landfill was built with a packed impermeable base and a drainage system for controlled drainage of leachate under the body of the landfill. The collected leachate is discharged into the shaft below the dam of the landfill and a special collector together with faecal water and local connections drains into the river Jala, which is about 4 km away. In 2017, households generated about 38,000 tons of mixed municipal waste.

The regional landfill "Mošćanica" Zenica started operating in 2008, and waste has been disposed of at this landfill for about 13 years. The regional landfill "Mošćanica" was built in the northern part of the landfill of the open pit mine "Mošćanica" and now covers an area of 24 ha. The landfill is located 14 km east of the town of Zenica. At the Regional Landfill "Mošćanica", waste is delivered from the area of the region consisting of the City of Zenica and the City of Visoko, and the municipalities of Travnik, Vitez, Busovača, Zavidovići, Žepče, and Novi Travnik. According to statistical data, the region served by the Regional Landfill "Mošćanica" has about 400,000 inhabitants. The amount of waste that was disposed of at this landfill in 2020 amounts to 65,880 tons. A leachate collection and treatment system and a leachate recirculation system have been established at this landfill. The treated leachate from this landfill is discharged into the stream or surface water.

Due to the different ages of landfills in these three local communities, i.e. different ages of estimated waters from the landfill, this paper will deal with the comparison of physical and chemical parameters of leachate from Sarajevo, Zenica, and Tuzla landfills. The analyzed results of leachate monitoring from these landfills in the Federation of BiH were performed by authorized laboratories. The implementation of leachate monitoring is carried out in accordance with the Regulation on the Conditions of Wastewater Discharge into the Environment and the Public Sewerage System (Official Gazette of FBiH 26/20). Physical and chemical parameters analyzed in the leachate from these three landfills are as follows: pH, total suspended solids, BOD_5, COD, total nitrogen (TN), total phosphorus (TP), chlorides, and sulfates.

RESULTS AND DISCUSSION

Table 1 presents the results of the physical and chemical analysis of leachate from the Sarajevo landfill. In 2016 and 2018, pH values were in the range of maximum allowable concentrations (MAC), while in 2017, the values of this parameter were above MAC.

Mean pH value in the period 2016-2018 amounted to 9.11, i.e. slightly higher than MAC or above 9. The total suspended substances in the three-year observation period had values below MAC, i.e. they met the Regulation on the Conditions of Wastewater Discharge into the Environment and the Public Sewerage System , (Official Gazzette of the Federation of BiH, No. 101/15, 1/16, and 101/18). The values of BOD_5 and COD as indicators of an organic load of leachate during the entire monitoring period had far higher values than MAC, i.e., than 25 mg O_2/l and 125 mg O_2/l, respectively. Furthermore, the values of total ni-

trogen (TN) and total phosphorus (TP) had far higher values compared to MAC prescribed by the above Regulation. Chloride and sulphate values were far less than MAC.

Table 1. Results of leachate monitoring from the landfill "Smiljevići" Sarajevo

Date of analysis(year)	2016	2017	2018	Average value	MAC*
pH	8.34	10.21	8.78	9.11	6-9
Total suspended matter (mg/l)	25.3	32.75	15.5	24.52	35
BOD5 (mgO_2/l)	380.4	410.27	851.53	547.40	25
COD (mgO_2/l)	1,290.8	1,555.1	2,818	1,887.97	125
Total nitrogen	142.51	113.09	1,358	537.87	15
Total fosfor (TP) (mg/l)	8.8	3.5	5.26	5.85	2
Chlorides (mg/l)	492.27	759.42	1,422	891.23	3,000
Sulfates (mg/l)	192.1	272.62	479.09	314.60	2,000

** Regulation on the Conditions of Wastewater Discharge into the Environment and the Public Sewerage System (Official Gazette of FBiH 26/20).*

Table 2 also presents the results of the physical and chemical analysis of leachate from the Tuzla municipal waste landfill. The pH values in 2016, 2017, and 2018 were in the range of maximum allowable concentrations, and the average value in this period was 7.52. The total suspended substances had an average value of 23.11 and were also within MAC. BOD_5 and COD values were above the limit values throughout the observation period. The values of total nitrogen were above the limits prescribed by the Regulation, while the values of total phosphorus were within the limits of the MAC. Chlorides in sulphates in the observed period had much lower values compared to those prescribed by the Regulation.

Table 2. Results of leachate monitoring from the landfill "Desetine" Tuzla

Date of analysis(year)	2016	2017	2018	Average value	MAC
pH	7.46	7.61	7.5	7.52	6-9
Total suspended matter (mg/l)	23.5	24.8	21.03	23.11	35
BOD5 (mgO_2/l)	148	95	270	171	25
COD (mgO_2/l)	501	327	840	556	125
Total nitrogen(TN) (mg/l)	220	94.5	646	320.17	15
Total phosphorus (TP) (mg/l)	0.6	0.59	0.75	0.65	2
Chlorides (mg/l)	672	211	820	567.67	3,000
Sulfates (mg/l)	22.3	17.9	56	32.07	2,000
Cu (mg/l)	0.07	0.019	0.018	0.04	
Zn (mg/l)	0.34	0.71	1.84	0.96	
Pb (mg/l)	0.22	0.05	0.13	0.13	
Mg (mg/l)	0.27	0.33	0.75	0.45	
Al (mg/l)	n/d	0.04	0.01	0.03	
Fe (mg/l)	n/d	n/d	4.3	4.3	

** n/d - no data provided*

The data related to the Zenica landfill are presented in Table 3. The pH value in the years of observation, from 2016 to 2018, was within the limits of the Regulation, and its average value is 8.28. The total

suspended substances all these years were above the limits of MAC, especially in 2017, where it was 725 mg/l. BOD_5 was also above the limits prescribed by the Regulation.Only in 2017 that overrun was very small, just 1.9mg/l above the limit. The COD value in 2016 and 2018 was extremely high, while in 2017, it was below the limit. As for the total nitrogen, in 2017, it was 2.83 and was below the limit, and in 2016 and 2017, it was extremely high. The values of total phosphorus have the same data for years as total nitrogen, which means that in 2017 it was below the limit and amounted to 0.26, and in 2016 and 2018, it was above the limits prescribed by the Regulation. In the observed period, the values of chloride and sulfate were extremely low in 2017 and 2018.For 2016 no data were submitted.

Table 3. Results of leachate monitoring from the landfill "Mošćanica" Zenica

Date of analysis (year)	2016	2017	2018	Average value	MAC
pH	8	8.27	8.56	8.28	6 – 9
Total suspended matter (mg/l)	290	725	41	352	35
BOD_5 (mgO_2/l)	463	26.9	682.3	390.73	25
COD (mgO_2/l)	1607	96	2320	1341	125
Total nitrogen(TN) (mg/l)	860.44	2.83	191.56	351.61	15
Total phosphorus (TP) (mg/l)	10	0.26	6.9	5.72	2
Chlorides (mg/l)	n/d	72.3	3119	1595.65	3,000
Sulfates (mg/l)	n/d	189.5	216.8	203.15	2,000
Cu (mg/l)	0.0134	0.001	0.05	0.02	
Zn (mg/l)	0.0287	0.06	0.15	0.08	
Cd (mg/l)	0.003	0.001	0.003	0.002	
Pb (mg/l)	0.0431	0.001	0.08	0.04	

** n/d–no data provided*

Table 4. Comparative presentation of monitoring results (average values per landfill)

Landfill	Smiljevići	Desetine	Mošćanica
pH	9.11	7.52	8.28
Total suspended matter (mg/l)(mg/l)	24.52	23.11	352
BOD_5 (mgO_2/l)	547.4	171	390.73
COD (mgO_2/l)	1887.97	556	1341
Total nitrogen (TN) (mg/l)	537.87	320.17	351.61
Total phosphorus (TP) (mg/l)	5.85	0.65	5.72
Chlorides (mg/l)	891.23	567.67	1595.65
Sulfates (mg/l)	314.6	32.07	203.15
Cu (mg/l)	n/d	0.04	0.02
Zn (mg/l)	n/d	0.96	0.08
Pb (mg/l)	n/d	0.13	0.04
Mg (mg/l)	n/d	0.45	n/d
Al (mg/l)	n/d	0.03	n/d
Fe (mg/l)	n/d	4.3	n/d
Cd (mg/l)	n/d	n/d	0.02

n/d–no data provided

Taking into account the assessment of pollution load caused by wild and locally unregulated solid waste landfills of different ages, in the absence of data on leachate monitoring, garbage composition, and

amount of disposal, when calculating pollution load, for landfills where solid mixed municipal waste is treated for more than 10 years, the composition of leachate is based on the average value of pollutants obtained from the average monitoring results of the Sarajevo landfill "Smiljevići", the landfill "Desetina" Tuzla and the landfill "Mošćanica".

Table 5. Expected value of pollutants inlandfills that are over 10 years old (Institute of Civil Engineering "IG" Banja Luka, 2019).

Parameter	Unit	Value
BOD_5	(mgO_2/l)	280
COD	(mgO_2/l)	1,100
Total suspended matter (mg/l)	(mg/l)	40
Total nitrogen	(mg/l)	300
Total phosphorus	(mg/l)	3
Chlorides	(mg/l)	730
Sulfates	(mg/l)	150
Cu	(mg/l)	0,03
Zn	(mg/l)	1.1
Cd	(mg/l)	0.05
Pb	(mg/l)	0.1
Mg	(mg/l)	0.5
Fe	(mg/l)	3.5
Al	(mg/l)	0.02

Based on the processed data (Tables 1, 2, 3, and 4), and in comparison with the expected values of pollutants in landfills that are over 10 years old (Table 5), we can state the following:

- Landfill "Smiljevići" Sarajevo, in the observed period of 3 years, has a higher average value than expected, namely: BOD5 (mgO2/l) - 547.40, compared to the expected value of 280 (mgO2/l), COD (mg O2/l) - 1887.97 (expected value 1,100). Also, higher than expected values are shown in the presence of Total Nitrogen (TN) (mgN/l) - 537.87 (expected value 300), then Total Phosphorus (TP) (mgP/l) - 5.85, Chlorides (mg/l) - 891.23, Sulfates (mg/l) - 314.60. A lower value than expected was recorded for the total suspended matter - 24.52. As for the other parameters, no data (n/d) were submitted for them.
- Landfill "Desetina" Tuzla, in the observed period of 3 years, has a higher average value than expected, as follows: Total nitrogen (TN) (mgN/l) - 320.17 (expected value 300), Cu (mg/l) - 0.04, Al (mg/l) - 0.03 and Fe (mg/l) - 4.3. In the case of other parameters, a lower value of the parameters than expected was recorded, while no data were submitted for one parameter.
- Landfill "Mošćanica" Zenica, in the observed period of 3 years, has a higher average value than expected, as follows: Total suspended solids - 352, BOD5 (mgO2/l) - 390.73, compared to the expected value of 280 (mgO2/l), COD (mg O2/l) - 1341 (expected value 1,100), Total nitrogen (TN) (mgN/l) - 351.61 (expected value 300), Total phosphorus (TP) (mgP/l) - 5.72, Chlorides (mg/l) - 1595.65 and Sulfates (mg/l) - 203.15. As for the other parameters, they had a lower value than expected, while data for three parameters were not submitted.

Based on all the above, and if we compare these three landfills, the landfill "Desetina" Tuzla had the best results of the analysis, which shows the smallest number of parameters that are above the expected value of pollutants in landfills that are over 10 years old.

For example, the following table 6 shows the results of the analysis, i.e. the physical and chemical parameters of the treated landfill leachate of J.P. Deponija d.o.o. Mostar.

Table 6. Results of physical and chemical analysis "J.P. Deponija d.o.o. Mostar"

Analyzed parameters	Unit of measurement	Analysis results
pH		7.6
Total phosphorus	mg/L	-
Chlorides	mg/L	5.83
Sulfates	mg/L	24.8
Mg	mg/L	230
Fe	mg/L	1713

Based on the results of physical and chemical analysis of "J.P. Deponija d.o.o. Mostar" and the results of the analysis of the three landfills presented in the paper ("Smiljević" Sarajevo,"Desetina" Tuzla,"Mošćanica" Zenica), we can see that the results are within the limits for leachate, which indicates a good treatment process.

CONCLUSIONS

Leachate from sanitary landfills is complex and heavily polluted wastewater. The composition and amount of leachate depends on many factors, which can vary precipitation, size and area of the landfill, type of waste, method of treatment, age of the landfill, etc. Due to the influence of many factors, the composition and amount of leachate vary considerably, which makes it very difficult to choose the appropriate treatment technology.

The only solution for municipal waste landfills is to treat them, but this requires significant material resources in order to comply with EU directives. Also, health and hygienic supervision of wastewater is being done, which, in addition to physical-chemical and toxicological analyzes, also includes a local inspection of the landfill, waste, and wastewater. A local inspection determines the general condition of the landfill and its surroundings. If the landfill meets the conditions of the local inspection, only then will the cleaning begin.

Based on the processed data (Tables 1, 2, 3 and 4), and in comparison with the expected values of pollutants in landfills that are over 10 years old (Table 5), we can conclude the following:

Regarding the landfill "Smiljevići" Sarajevo, in the observed period of 3 years, a total of 8 physical and chemical analyzes were performed, while data for 7 were not submitted. The results tell us that 7 parameters had higher average values than expected, while for only one parameter the value was lower than expected.

In the case of the landfill "Desetina" Tuzla, in the observed period of 3 years, a total of 14 physical and chemical analyzes were performed, while data for 1 were not submitted. The results tell us that for 4 parameters, higher average values were determined than expected, while for 10 parameters the value was lower than expected.

Regarding the landfill "Mošćanica" Zenica, in the observed period of 3 years, a total of 12 physical and chemical analyzes were performed, while data were not submitted for 3. The results tell us that 7 parameters showed higher average values than expected, while for 5 parameters the value was lower than expected.

As a conclusion to all the above, the basic steps in the process of leachate treatment that need to be taken into account are hereby listed again:

- Landfill treatment technology must be applied to reduce leachate production,
- Control of waste transport and disposal at landfills can improve leachate quality,
- The possibility of pre-treatment and connection to the local PTOV or other industrial wastewater treatment plants (if any) as a long-term option is considered/assessed at the site.

Selecting a leachate treatment process is a complex task and requires reliable data for analysis and final selection.

CONFLICT OF INTEREST
The authors declare no conflict of interest.

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