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How to Choose Pollution Indicators for Monitoring Landfill Leachates †

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† Presented at the 9th Innovations-Sustainability-Modernity-Openness Conference (ISMO'20), Bialystok, Poland, 20–21 May 2020.

Published: 5 August 2020

Abstract: Leachates are one of the main factors polluting the ground and water environment in the vicinity of landfills. This is connected with the need to systematically control the elements of the environment that are exposed to the negative impact of landfill emissions. In Poland, the scope of landfill leachate quality monitoring includes 10 obligatory parameters (pollution indicators). The paper presents an example of the application of selected statistical methods (basic statistics, statistical tests, principal component analysis) to assess the impact of individual pollution indicators on the quality of landfill leachates. Four landfills from the area of Lower Silesia were selected for analyzes, for which in the years 2018–2019 tests of leachate properties were conducted in an extended scope (in relation to the scope applicable during monitoring). Analyses of the obtained results showed significant differences between landfills, depending mainly on their age and method of operation. Specific factors for assessing differences between landfills were as follows: electrolytic conductivity, chemical oxygen demand ($COD_{(Cr)}$), organic nitrogen, ammonium nitrogen, chlorides and calcium. The values of some of the parameters included in the monitoring studies did not show variability, remaining below the limit of quantification. The conducted analyses permit the determination of the level of leachate contamination from selected landfills and the proposal of indicators that could complement the monitoring range of landfills for many years.

Keywords: municipal waste landfills; leachate; pollution indicators

1. Introduction

Leachate formation is one of the many environmental hazards associated with landfilling [1]. A leachate can be defined as a fluid that seeps through a landfill and is discharged from or contained in a landfill [2].

The leachate contains soluble organic and inorganic compounds, suspended particles and heavy metals [3]. As a result of the physical, chemical and microbiological processes taking place inside the landfill, the leachate takes over a number of substances, and as a result it becomes a highly polluted wastewater [4,5]. The composition of the leachate is dynamic and variable in time, depending on, among others, the nature of the deposited waste and the chemical and biochemical decomposition processes taking place in it [6], the stabilisation level of the deposited waste, the collection system, as well as the location of the landfill and hydrological factors [7,8].

Since leachates resulting from landfilling activities are considered to be among the main contaminants of the soil and water environment, there is a need to control the state of the environment in their surroundings [9,10].

In Poland, the scope, time, frequency, method and conditions of monitoring are specified in the Regulation of the Minister of the Environment of 30 April 2013 on the landfill of waste. On its basis, the state of the water environment in the vicinity of the municipal waste landfill site is assessed at particular stages of its operation. In the operational and after-care phase, landfill leachate tests are carried out, covering 10 indicator parameters. No studies are required to establish a set of parameters for the monitoring of a landfill leachate. It is possible to select additional parameters, but due to the costs, landfill managers most often order tests only within the binding scope.

The aim of the study was to assess the impact of individual pollution indicators on the quality of landfill leachates. Four landfills from the area of Lower Silesia were analyzed, for which in the years 2018–2019 tests of leachate properties were carried out in an extended scope (compared to tests under monitoring).

2. Materials and Methods

2.1. Study Area

Four non-hazardous and inert waste landfills were selected for research. The facilities are located in south-western Poland, in the Lower Silesian voivodeship. All landfills have leachate capture and disposal facilities. Two landfills are closed down (landfills in Bielawa and Wrocław); the other two are operational landfills (landfills in Legnica and Jawor).

2.2. Chemical Composition of Leachates

The analysis of the quality of landfill leachates was carried out in 2018–2019. In the leachate samples, the following were determined: pH, electrical conductivity (EC), chemical oxygen demand ($COD_{(Cr)}$) and concentration: total Kjeldahl nitrogen (TKN), organic nitrogen (ON), ammonium nitrogen (AN), total dissolved solids (TDS), total suspended solids (TSS), suspensions, sulphates, chlorides, sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), chromium (Cr), lead (Pb), nickel (Ni) and cadmium (Cd). Samples were taken every 3–4 months.

The results of landfill leachate composition tests were subjected to statistical analysis using Statistica 13.1 (StatSoft Poland, StatSoft, Inc., Tulsa, OK, USA). To assess the significance of chemical composition differences between the groups of operational and closed landfills, Mann–Whitney U test (nonparametric test) were used. The principal components analysis (PCA) was used to indicate which of the pollution indicators best characterized the composition of the leachate.

3. Result and Discussion

Table 1 presents the results of the analysis of differences between the values of selected indicators of leachate contamination from operational and closed landfills. Statistically significant differences characterized: EC, $COD_{(Cr)}$, TKN, ON, AN, TDS, TSS, suspensions, sulphates, chlorides, Na, K, Ca, Mg and Ni. No significant differences were found between the concentrations of other heavy metals (Cu, Zn, Cr, Pb, Cd), in spite of the changes observed in the literature following the landfill age [1].

Table 2 presents the results of the principal component analysis (PCA) for the chemical composition of leachates from operational municipal waste landfills. The analysis showed the presence of five components that explained a total of over 80% of the variability of test results. These components showed a strong correlation with EC, $COD_{(Cr)}$, ON, AN, TSS, chlorides, Ca, Fe, Zn, Cr, Pb and Ni.

Table 1. Analysis of differences between the leachate composition of closed and operational landfills (the highlighted results are significant with $p < 0.05$).

Variable	Sum of Ranks		U	Z	p
	Closed	Operational			
EC	105.0	301.0	0.0	−4.480	0.00001
$COD_{(Cr)}$	145.0	261.0	40.0	−2.642	0.00824
TKN	111.0	295.0	6.0	−4.204	0.00003
Suspensions	155.0	251.0	50.0	−2.183	0.02907
Sulphates	248.0	158.0	53.0	2.045	0.04089
Chlorides	129.0	277.0	24.0	−3.377	0.00073
Sodium	137.0	269.0	32.0	−3.010	0.00262
Nickel	126.0	280.0	21.0	−3.515	0.00044

U—test statistic for a small sample size, Z—test statistic for a small sample size, *p*—significance level for the value of test statistics Z, EC—electrical conductivity, COD—chemical oxygen demand, TKN—total Kjeldahl nitrogen.

Table 2. The results of the principal component analysis (PCA) analysis for leachates from operational landfills.

Number of Principal Component	Eigenvalues	% of Total Variance	Cumulative Eigenvalue	Cumulative % of Total Variance
1	7.193	31.273	7.193	31.273
2	4.263	18.533	11.456	49.807
3	3.041	13.221	14.496	63.028
4	2.405	10.457	16.902	73.485
5	2.071	9.006	18.973	82.491

Table 3 presents the results of the PCA for the chemical composition of leachates from closed municipal waste landfills. The analysis showed the presence of five components that explained a total of almost 80% of the variability of test results. These components showed a strong correlation with EC, $COD_{(Cr)}$, TKN, ON, AN, TDS, chlorides, K and Ca.

Table 3. The results of the PCA analysis for leachates from closed landfills.

Number of Principal Component	Eigenvalues	% of Total Variance	Cumulative Eigenvalue	Cumulative % of Total Variance
1	9.317	40.508	9.317	40.508
2	3.254	14.148	12.571	54.656
3	2.091	9.090	14.662	63.746
4	1.835	7.979	16.497	71.725
5	1.735	7.546	18.232	79.271

The results of the PCA analysis showed that for the description of leachate properties from operational and closed landfills, pollution indicators such as EC, $COD_{(Cr)}$, ON, AN, chlorides, and Ca were best. These parameters are specified in the literature as characteristic for leachates from municipal waste landfills [11], but for the most part, the parameters fall outside the obligatory monitoring range.

4. Conclusions

The conducted analysis showed the existence of significant differences between the surveyed active and closed landfills. These differences were especially visible in the cases of the following: EC,

$COD_{(Cr)}$, TKN, suspensions, sulphates, chlorides, sodium and nickel. No significant differences were found between the concentrations of other heavy metals (Cu, Zn, Cr, Pb, Cd) analyzed as part of the monitoring. EC, $COD_{(Cr)}$, ON, AN, chlorides and Ca appear to be particularly useful for monitoring purposes. These parameters are specified in the literature as characteristic of leachates, and in the conducted tests they also clearly showed differences between the tested landfills.

Author Contributions: A.W. and A.S.-P. conceived and designed the experiments; A.W. performed the experiments; A.W. and A.S.-P. analyzed the data; A.S.-P. contributed reagents/materials/analyzes tools; A.W. wrote the paper. All authors have read and agreed to the published version of the manuscript.

Funding: This research and the APC were funded by a targeted subsidy for research and development of young scientists and PhD students at the Faculty of Environmental Engineering and Geodesy of the Wrocław University of Environmental and Life Sciences—contract No. B030/0104/18.

Conflicts of Interest: The authors declare no conflict of interest.

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