Original article

Assessment of changes in the quality of ground water in the area of landfill site in Poczesna (South Poland) using the LWPI index

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ABSTRACT

Municipal waste landfill is a potential, or actual, source of groundwater pollution. Even landfill with a ground containment system can generate leachate that will migrate to aquifers. In this context, it is important to monitor water and leachate and to rationally analyze the existing situation. The purpose of this article was to assess groundwater contamination in the region of the municipal landfill site in Poczesna (Southern Poland) using the Landfill Water Pollution Index (LWPI). Certain physicochemical parameters such as pH, electrical conductivity (EC), total organic carbon (TOC), polycyclic aromatic hydrocarbon (PAH), Cd, Pb, Zn, Cu, Cr, and Hg, were analyzed from samples from six piezometers in the years 2015-2019. The LWPI index values in the groundwater samples ranged from 0.97 to 3.11 ($P < 0.05$). Indicator values that are within the range 2-5 reflect poor water quality with a high visible landfill impact, and those > 5 suggest strongly polluted water with a very high landfill impact. The results of this study indicated that the quality of the groundwater in the area around the landfill was better in the case of the Jurassic aquifer compared to the Quaternary aquifer. The results provided by this index are very useful in the context of a quick assessment of groundwater quality. For the purposes of further risk analyses, it is important to consider other variables (chemical components) which can influence groundwater quality in the region of municipal landfill sites.

KEY WORDS: landfill, waste, LWPI index, hydrogeology

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1. Introduction

Data on the municipal economy in Poland show that the thermal processing of municipal waste is developing dynamically. In 2018, almost 23% of the municipal waste generated was intended for thermal processing for energy recovery (CZOP, 2020). Although economic development has a significant impact on the level of waste generation (MINELGAIĆ & LIODIKIENĖ, 2019), landfilling is still one of the most popular methods used for the disposal of discarded materials (VAVERKOVÁ & ADAMCOVÁ, 2015; WONG ET AL., 2015; VAVERKOVÁ ET AL., 2018A) causing repeated land degradation (VAVERKOVÁ ET AL., 2018B). Land degradation is not the only negative effect of landfill. If landfill is incorrectly secured

and improperly operated, it can pose a threat to soil (DELANG, 2017) and groundwater quality (BHALLA ET AL., 2012; DĄBROWSKA ET AL., 2018). Leachates constitute a complex matrix of various chemical substances: organic matter, inorganic components, heavy metals (PRZYDATEK & KANOWNIK, 2019).

The current legal arrangements, i.e., Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste, and the Polish Regulation of the Ministry of the Environment of 30 April 2013 (Journal of Laws, No. 523) on landfill, impose an obligation to conduct monitoring in the region of municipal landfill sites. Monitoring of groundwater has a strategic role (ESMAELIAN ET AL., 2018) in these waters in the supply of drinking water and it is related to their protection and qualitative

activities (WITKOWSKI & DĄBROWSKA, 2017). Without reliable information on groundwater quality, it is not possible to undertake comprehensive and rational management of the entire water economy. It is necessary to conduct reliable groundwater monitoring (quality and quantity), which will allow for a proper assessment of the impact of the pollution source on groundwater and in planning ways to counteract the negative effects (GRATH ET AL., 2000; NIELSEN, 2006; QUEVAUVILLER ET AL., 2009). The law defines the minimum number of piezometers and their location in the hydrodynamic system as well as the sampling frequency and minimum range of the field and laboratory tests in relation to specific EC, pH, TOC, Cu²⁺, Zn²⁺, Pb²⁺, Hg²⁺, Cd²⁺, Cr⁶⁺ and PAHs (BOJAKOWSKA, 1994).

Such a small range of determinants allows the use of mathematical indicators that may be useful for the assessment of groundwater vulnerability (WITKOWSKI & KOWALCZYK, 2004) to pollution and for the assessment of groundwater quality in the area of pollution sources. It should be noted that in the case of industrialized areas, it is possible to determine specific vulnerability (SOŁTYSIAK ET AL., 2018). There are lots of methods which allow the assessment of groundwater vulnerability to contamination (VRBA & ZAPOROZEC, 1994; WACHNIEW ET AL., 2016), including estimation methods, parameter methods, ranking methods, modelling, neural networks and statistical methods (MACIEJEWSKI ET AL., 2006; LEIBUNDGUT ET AL., 2009; OKE ET AL., 2016; SOŁTYSIAK & DĄBROWSKA, 2016; NOURANI ET AL., 2017; BAGHANAM ET AL., 2020). Assessment of the vulnerability of water to pollution also takes into account elements of the risk assessment using the following phases: planning, acquisition, development, testing, proper placement of IT systems (PRITCHARD, 2013).

There are lots of studies which have proposed different indices for groundwater risk assessment (GIBRILLA ET AL., 2011; MOR ET AL., 2018). The most popular index probably is Horton's water quality index (BIEDKA & TALALAJ, 2016). The Backman pollution index is also quite popular (BACKMAN ET AL., 1998; DĄBROWSKA ET AL., 2018; KRČMAR ET AL., 2018). Indices are an effective way of providing information about the quality of the water for citizens and policy makers (ZHAO ET AL., 2018). It is worthwhile to note that indices help in classifying groundwater and effectively determining the properties of water (WU ET AL., 2010). Unfortunately many indicators are not applicable to groundwater in the area of pollution sources due to the need for too much data, too large a range of parameters, or the necessary amount of tests to be performed for the studied area. It should be borne in mind that in the case

of landfill, usually only the scope of tests specified in the regulations is performed. Also in the case of landfill, groundwater quality assessment requires a consideration of the spatial and temporal variability of the monitored components. Hence, it is very difficult to assess the real impact of landfill on groundwater quality (KUMAR & ALAPPAT, 2005).

One of the methods for the mathematical description of groundwater susceptibility to pollution is the use of an indicator specifying the degree of groundwater pollution in relation to the value of individual components in the inflow of groundwater to the landfill area. This indicator is the Landfill Water Pollution Index (TALALAJ, 2014). This index takes into account 10 parameters which should be obligatorily monitored in groundwater in the region of municipal landfill in every phase of their exploitation. Due to the availability of such data, it is possible to calculate the index for each pollution source that is monitored.

Therefore, the authors hypothesized that the use of the LWPI index would enable the description of pollution in the region of the landfill in Poczesna. The aim of this study was to identify changes in the physical and chemical components of groundwater on the basis of the values of the LWPI index for six observation points belonging to the monitoring network of the municipal landfill in Poczesna (Southern Poland) in 2015-2019.

2. Study area

The landfill for non-hazardous and inert waste is located in the municipality of Poczesna, in the Silesian Province (Southern Poland). In terms of physical and geographic regionalization, the research area is located in the Polish Upland Province, the Silesian-Krakow Upland Sub-Province, the Kraków-Częstochowa Upland Macroregion and the Upper Warta Lowering Mesoregion (KONDRACKI, 2009). The Sobuczyna stream flows west of the landfill, and the River Brzezinka flows to the north (Fig. 1).

The total area of the landfill is 128.4 ha. The landfill was established in 1983. It was then that the construction of the first landfill site began, in the post-exploitation areas of iron ore mines, in particular in the areas of storage of flint rocks mined in the neighboring iron ore mines. The first site with an area of 16.8 hectares is currently closed and reclaimed, while storage site II, is currently approved for use and has an area of 7.77 hectares. The first site, unlike the second one, does not have a ground protection system (DIEHL, 2015). The landfill is equipped with a leachate collection and drainage system, as well as a degassing and landfill gas utilization system. The

bottom of the new site was sealed with a 2 mm thick PEHD geomembrane, while the leachate drainage branches were made of perforated PVC pipes with a diameter of 80 mm.

The waste is stored above the level of the ground, in longitudinal layers up to a height (after compaction) of 1.85 m, then it is covered with an insulating layer with a thickness of 0.15 m made of waste approved for recovery, or mineral material. The cycles are repeated 9 times until an elevation of 18 m above the terrain elevation measured at the base of the landfill sites is reached, this is then followed by coverage of the deposited waste with a layer of earth or inert material. The leachate captured by the drainage system from the waste storage sites, amounting to approx. 49,100 m³/ year, is directed through an underground collector to the leachate tank. Wastewater from the leachate tank is treated in a membrane treatment plant, used for sprinkling the waste, then discharged into the catchment basin of the water supply or discharged via the sewage system.

There is also a Waste Management Plant in the area of the landfill, consisting of a municipal waste sorting plant, waste composting plant, bulky waste demolition station, construction debris shredding station, and a municipal hazardous waste collection point (<http://www.czpk.czestochowa.um.gov.pl/>).

The landfill site is located within the Silesian-Kraków monocline. Formations of the older subsoil fall towards the north-east, towards the axis of the Miechów Trough. Triassic formations lie directly on the Palaeozoic sediments. The Lower Jurassic sediments are represented by sands and sandstones. Middle Jurassic sands and iron sandstones, are the so-called Kościelisko layers. Protection against contamination of groundwater is provided by a well-insulating complex of Doggerian clay with a thickness of 30-35 m (MASZCZYŃSKA & TRZESZCZYŃSKA, 2003). On the Jurassic formations, there are Quaternary sediments composed mainly of sands with an admixture of gravel, silt and tills (BARDZIŃSKI ET AL., 1986).

Fig. 1. Map of the study area (based on Topuszczak, 2018)

The analyzed area of research is located within Groundwater body number 99, which has four aquifers - Quaternary, Cretaceous, Jurassic and Triassic (ZEMBAL ET AL., 2010). In the area of the landfill, only two aquifers deserve attention, i.e. Quaternary and Jurassic.

The groundwater monitoring network consists of six piezometers (two monitoring the Quaternary aquifer - Cz-1, Cz-2 and four monitoring the Jurassic aquifer - K-1 - K-4). The K-1 piezometer is located at the inflow of waters to the landfill, the Cz-2 piezometer is located west of the landfill, and the K-3 piezometer to the east. The remaining piezometers are located at the outflow of groundwater from the landfill (Fig. 1).

The Quaternary aquifer is characterized by its small thickness and includes water of a poor chemical state. Water taken with piezometers Cz-1 and Cz-2 has a lowered pH, which means that they should be included in the fourth quality class. The Middle Jurassic level is formed in fractured, fissured sandstones as well as sands and gravels, the thickness of which varies between 20-40 m. The waters of this aquifer are characterized by the concentration of most of the components typical for quality class I or II, but the pH value indicates class IV (Regulation of the Minister of Maritime Economy and Inland Navigation of 11 October 2019 on the criteria and method of

assessing the state of groundwater bodies, Journal of Laws 2019, item 2148).

The groundwater table is located at a depth of approx. 1 m below ground level for the Quaternary aquifer (piezometer Cz-2) and up to 9 m below ground level for the Jurassic aquifer (K-4 piezometer).

3. Methodology

This study investigates the physicochemical and chemical parameters in groundwater on the basis of monitoring data gathered from the piezometers belonging to the observation network of the municipal landfill in Poczesna between 2015-2019. Six piezometers (Cz-1, Cz-2, K-1, K-2, K-3, K-4) were installed in accordance with the movement of groundwater and are located downstream from the landfill. For further analyzes, all parameters that are mandatory for the monitoring of groundwater in the area of landfills, were used (EC, pH, TOC, Cu^{2+} , Zn^{2+} , Pb^{2+} , Hg^{2+} , Cd^{2+} , Cr^{6+} and PAHs). The tested values for individual parameters have a normal distribution (based on Lilliefors test) with significance correction value > 0.2 . Dell Statistica 13 program was used to analyze the data.

The scope of the monitoring studies carried out around the landfill dictated the choice of the quality index for groundwater impacted by a landfill which was the LWPI index (BAGHANAM ET AL., 2020). The calculation of this index was performed using the equation proposed by TALALAJ (2014). In this equation S_i is calculated based on values of C_p and C_b using formula (1).

$$S_i = \frac{C_p}{C_b} \quad (1)$$

where:

C_p is the concentration of the i th parameter in each of the samples

C_b is the concentration of the i th parameter in the inflow groundwater sample.

Based on these calculated ratios, individual weights for the parameters were selected and the final values of the index were calculated using the formula (2).

$$LWPI = \frac{\sum_{i=1}^n S_i w_i}{w_i} \quad (2)$$

where:

w_i is the weight of the i th pollutant variable,

n is the number of groundwater pollutants.

The weight values were calculated for parameters on the basis of TALALAJ (2014). Detailed data is presented in Table 1.

Table 1. Weights of parameters required to calculate LWPI

Parameter	Required weight (w_i)	Proposed weight (w_i)
EC	1	5
pH	2	2
PAHs	5	1
TOC	4	4
Pb, Cu, Cr, Hg, Zn, Cd	3	3
Sum of weights	30	30

The value of the contamination index increases along with an increase in the concentration of individual parameters (DĄBROWSKA ET AL., 2018). An index value greater than 3 suggests heavily transformed areas. The interpretation of the LWPI value is as follows:

- ≤ 1 - water under no landfill impact
- $(1 < LWPI \leq 2)$ - moderately polluted water due to a small landfill impact
- $(2 < LWPI \leq 5)$ - poor water with high visible landfill impact
- > 5 - strongly polluted water (TALALAJ, 2014).

Data from the K-1 piezometer were used as reference values for the inflowing waters. Due to the fact that monitoring of the Quaternary aquifer consists of only two piezometers, the data from these points were not included in the LWPI main calculations, and served only for comparative purposes, if the geochemical background was also the value from the piezometer capturing the Jurassic aquifer.

In order to compare how the number of observation points and the LWPI value affect the general interpretation of groundwater quality in the area of landfill, the value of this indicator was interpolated using a kriging method (NIELSEN & WENDROTH, 2003). Kriging is one of the simplest and most effective interpolation methods (KOKESZ, 2010). This method can be used with diverse datasets.

4. Results and discussion

Values of EC, pH, TOC, Cu^{2+} , Zn^{2+} , Pb^{2+} , Hg^{2+} , Cd^{2+} , Cr^{6+} and PAHs were applied for determination of groundwater status and were also used for calculations of LWPI values for piezometers of the Jurassic aquifer. For the groundwater, mean values for the most significant physicochemical parameters are shown in Table 2.

The pH values for all groundwater samples were lower than 7. In most cases the measured value indicated a water quality class of IV (poor chemical status). In terms of the electrical conductivity of

water from K-1 and K-2 piezometers, these should be classified as class I, and in the case of K-3 and K-4 piezometers as class III. The TOC and PAHs are parameters of dissolved organic matter in the analyzed groundwater samples. TOC values in the water of the Jurassic Floor mean that these waters are classified as class 1. The same is the case with PAHs. It is worth noting that for most landfill sites the value of the PAHs parameter is below the limit of quantification. This proves that it should not be taken into account as a typical indicator of pollution in the area of municipal waste landfill sites (DĄBROWSKA ET AL., 2018). The concentration of heavy metals in groundwater near the analyzed landfill was relatively low. The highest concentrations of metals were observed

in the case of copper. The list of the minimum, maximum and average results for individual parameters can be found in Table 3.

Analytical results for the Landfill Water Pollution Index values (with required and proposed weights) for the analyzed landfill are shown in Table 4.

The obtained values of the index show that the waters of the Jurassic floor belong to moderately polluted water due to a small landfill impact. In the analyzed time period, the values of the indicator for water without landfill impact were found to be twice those for the K-4 piezometer. The indicator showing poor water with a high visible landfill impact was obtained once for the piezometer located farthest north of the K-2 facility (outflow zone).

Table 2. Basic statistics for the selected parameters in groundwater

Parameter	Unit	Cz-1	Cz-2	K-1	K-2	K-3	K-4
pH	-	6,88	6,65	6,4	6,09	6,05	6,33
EC	μS/cm	1916,75	1776,45	327,8	346,65	773,65	874,25
TOC	mg/l	11,39	10,14	1,012	1,33	2,194	1,45

Table 3. Minimum, maximum and average results for individual parameters

Piezometer	2015	2016	2017	2018	2019
K-1	1	1	1	1	1
K-2	1,26/1,23	2,14/1,68	1,08/1,10	1,24/1,26	1,58/1,56
K-3	1,28/1,28	1,27/1,53	1,81/1,37	1,04/1,26	1,75/1,33
K-4	1,22/1,33	1,21/1,42	0,98/1,24	1,03/1,27	0,97/1,32

Table 4. LWPI values in piezometers monitoring the Jurassic aquifer in the years 2015-2019

Piezometer	2015	2016	2017	2018	2019
Cz-1	1,9/2,39	2,96/3,14	3,11/3,57	3,06/3,79	2,67/3,58
Cz-2	1,58/1,90	2,88/3,04	2,97/2,52	2,95/3,62	2,64/3,42

The LWPI pollution index takes into account those parameters that are necessary for monitoring the quality of groundwater in the area of a landfill site. Analyzing the obtained results for the Jurassic aquifer, it can be concluded that the described landfill does not pose any threat to groundwater.

The selection of weights for the indicator can be viewed with a critical eye, as it is the EC value that largely indicates water pollution. Certainly the weights for EC and PAHs should be reversed. Due to the fact that PAHs are not typical indicators of pollution for municipal waste.

Different results were obtained when calculating the pollution index for piezometers monitoring the Quaternary aquifer. Unfortunately, there is no localized piezometer monitoring the Quaternary aquifer at the inflow of water to the landfill area.

In order to illustrate the variability of the index, a hydrochemical background was used, based on data from the K-1 piezometer. The LWPI values (with required and proposed weights) for piezometers monitoring the Quaternary floor are summarized in Table 5.

The LWPI values for the Quaternary aquifer (except for 2015) indicate that we are dealing with poor water with a high visible landfill impact. It is worth noting that the index values show an upward trend. Higher values of the index were observed in the piezometer located on the line of water flow from the old closed quarters than in the piezometer located west of the second quarter. It should be emphasized, however, that this is mainly determined by the TOC value, which is higher in the water of the Cz-1 piezometer.

Table 5. LWPI values in piezometers monitoring the Quaternary aquifer in the years 2015-2019

Year	Parameter Unit	pH	EC	TOC	Cu	Zn	Pb	Cd	Cr	Hg	PAHs
		-	$\mu\text{S}/\text{cm}$	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	$\mu\text{g}/\text{l}$	$\mu\text{g}/\text{l}$
2015	Max	6.58	1847.75	4.75	<0.031	0.2145	<0.005	<0.00053	<0.01	<0.05	<0.030
	Min	6.34	346.75	1.05	<0.010	0.051	<0.005	<0.0004	<0.01	<0.05	<0.030
	Avg	6.44	954.21	2.7	-	0.096	<0.005		<0.01	<0.05	<0.030
2016	Max	7	2237	11 $\pm$ 2	<0.004	0.091	<0.004	0.00084	<0.01	<0.10	0.0103
	Min	6	312	<2.0	<0.004	0.01	<0.004	0.000265	<0.01	<0.10	<0.0050
	Avg	6.45	1119.5	-	<0.004	0.034	<0.004	0.00039	<0.01	<0.10	-
2017	Max	7.1	1392	14	0.0075	0.065	<0.004	0.0007	<0.010	<0.10	<0.0050
	Min	5.8	270	<2.0	<0.004	0.006	<0.004	<0.0005	<0.010	<0.10	<0.0050
	Avg	6.3	770	-	-	0.026	<0.004	-	<0.010	<0.10	<0.0050
2018	Max	6.93	1961	13.8	0.007	0.078	<0.009	<0.0005	<0.01	<0.1	<0.005
	Min	5.85	304.75	<2.0	<0.004	0.012	<0.004	<0.0005	<0.01	<0.1	<0.005
	Avg	6.27	1019.58	-	-	0.028	-	<0.0005	<0.01	<0.1	<0.005
2019	Max	6.9	2347	12	<0.004	0.128	<0.023	<0.001	<0.01	<0.1	<0.028
	Min	6	302	<2.0	<0.004	<0.024	<0.004	<0.001	<0.01	<0.1	<0.006
	Avg	6.53	1149.7	-	<0.004	-	-	<0.001	<0.01	<0.1	-

The strength of the potential relationship among the index values was determined through correlation analysis at a significance level of $P < 0.05$. In particular, a significant and positive relationship was found between Cz-1 and Cz-2 piezometers ($r=0.99$). The calculated values showed only partial differences between the Quaternary and Jurassic piezometers.

The results of the obtained indicators are rather low, compared, for example, to the work of TALALAJ (2014). The obtained indicator values are about 4 times lower.

Figure 2 shows the isoline distribution of this indicator for all piezometers located in the observation network of the landfill (A) using required weights and the isoline distribution of this indicator only for piezometers monitoring the Jurassic aquifer (B) using the kriging method. Additionally, analogous data sets are presented in Figures C and D, but with the use of the weights proposed earlier.

Interpolation for selected observation points covered the entire study area, regardless of the number of piezometers included. When interpolating the index values for 4 and 6 points, a different isoline pattern was obtained in the western part of the analyzed area. The results of the analysis of the obtained maps indicate that reducing the number of piezometers by 2 resulted in a change in arrangement of the isolines, simplifying the distribution of the indicator used. Additionally, the distribution shown in Fig. 2B appears to be

more reliable. This is also due to the fact that all interpolation methods lose their accuracy when analyzing data from points located close to each other. This is the case for the Cz-1 and K-4 piezometers. The change in weights for EC and PAHs parameters resulted in an increase in LWPI indices for piezometers capturing the Quaternary aquifer. In the case of piezometers capturing the Jurassic aquifer, significant changes were observed only in the case of the K-4 piezometer. A slightly different arrangement of isolines is presented by the map with interpolation only for piezometers capturing the Jurassic aquifer (Fig. 2). In the case of interpolation for the entire observation network, the pattern of isolines remains practically unchanged (Fig. 2C).

It often happens that the measurement points are located too close, or too far from each other, so the results of chemical analyzes do not reflect the actual hydrogeochemical conditions of a given area. For better accuracy and assessment of the impact of this landfill on groundwater, other physicochemical parameters should also be taken into account (apart from the absolute minimum) and another piezometer should be drilled which is located at the groundwater inflow to the landfill and which would monitor the Quaternary aquifer.

It should be remembered that when using the interpolation method in an automatic manner, one must also refer to hydrogeological knowledge from the studied area in order not to make any interpretation errors.

Fig. 2. Distribution of LWPI values in the studied area: A - for piezometers capturing the Quaternary and Jurassic aquifer; B - for piezometers capturing only the Jurassic aquifer

Conclusions

Facilities that constitute potential, or actual pollution sources, such as waste landfill sites, should have a monitoring network enabling the assessment of the chemical status of groundwater in their area. The extent and magnitude of the impact of a landfill on groundwater can be assessed using a variety of methods, including vulnerability or risk analysis methods. One example of a mathematical description of the impact of landfills on groundwater is the Landfill Water Pollution Index. The scope of the physicochemical parameters used for its calculation complies with the applicable law. This allows the calculation of this measure for each site. However, it seems reasonable to change the parameters used and to extend the indicator to other, more characteristic indicators of groundwater pollution in the area of landfill (e.g. chlorides, sulphates, ammonium ion). It is also debatable to assign fairly low weights to

parameters such as EC or pH, and relatively large PAHs or heavy metals, which are often absent in most known municipal landfill sites.

The calculations performed show that the waters of the Jurassic aquifer at the study site are not likely to be endangered by the landfill, as its impact is quite low. However, taking into account the results obtained for the two piezometers monitoring the waters of the Quaternary aquifer, they have poor water quality with high visible landfill impact. It should be noted once again that these are assessments made on the basis of the scope of this indicator.

In order to obtain reliable and representative results of groundwater quality monitoring tests, an observation network appropriate to the hydrogeological and spatial conditions should be constructed. The spatial quality is ensured by the location of measurement points covering the entire research area.

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