Acta Sci. Pol.
Formatio Circumiectus 20 (1) 2021, 43–54
ENVIRONMENTAL PROCESSES

www.acta.urk.edu.pl/pl ISSN 1644-0765 DOI:

ORIGINAL PAPER Accepted: 8.04.2021

ASSESSMENT OF CHANGES IN THE QUALITY OF GROUNDWATER IN THE REGION OF THE MUNICIPAL LANDFILL IN WOJKOWICE

Radosław Karkocha

Faculty of Natural Sciences, University of Silesia, Będzińska 60, 41-200 Sosnowiec

ABSTRACT

Aim of the study
Landfilling is an activity, which may threaten the destruction or contamination of the soil and water environment. Pollution can be generated both by leachate and by landfill gas. Legal conditions impose on landfill managers to monitor groundwater around the landfills. The impacted soils and groundwater show high chlorides, sulphates, heavy metal concentrations especially as compared to natural hydrochemical background values. Monitoring results can be analyzed using pollution indicators. The objective of this study was to determine the quality of groundwater in a landfill in Wojkowice (southern Poland) using the Backman index.

Material and methods
The novelty of the paper results from the use of a different range of parameters than initially included in the formula. The results of water quality monitoring for three piezometers from 2013–2020 were considered. The contamination index was calculated separately for each of the analysed water samples, taking into account the electrolytic conductivity and the concentration of total organic carbon (TOC), Cd, Pb, Zn, Cu, Cr and the sum of $N\text{-}NO_3$, $N\text{-}NO_2$ and $N\text{-}NH_4$.

Results and conclusions
The Backman index values range in the groundwater samples were –5.3 to 603. The value of the Backman index increases with the increase in the concentration of individual parameters in groundwater. In the case of heavily transformed areas, the water pollution index has high values, exceeding 3. The results of this index indicated that the quality of the groundwater around the landfill is bad. In the future, it is planned to expand the range of parameters for calculating the index.

Keywords: landfill, waste, Backman index, hydrogeology, Wojkowice, Poland

INTRODUCTION

Landfilling is the most popular method for waste disposal (Vaverková and Adamcová, 2015; Dąbrowska et al., 2018a; Dąbrowska et al., 2018b). This mainly affects developing countries (Hussein et al., 2021), but is also common worldwide (Renou et al., 2008). The greatest threat to the soil and water environment in the case of landfills is leachate (Naveen et al., 2017; Dąbrowska et al., 2019; Rykała and Dąbrowska, 2020). Legal regulations regulate the necessity to create ground protection systems when creating landfills, but it was not practiced in the past (Wong et al., 2015). Due to the lack of a liner system, many landfills have been closed, but the fact that they are still in operation is not synonymous with the environmental risk they still pose (Mor et al., 2018). This is related to the migration of pollutants from leachate, which are

✉e-mail: e-mail: r.karkocha1@gmail.com

generated because of the infiltration of precipitation into the landfill body (Elbl, et al., 2015; Sołtysiak and Dąbrowska, 2016; Minelgaitė and Liobikienė, 2019).

The monitoring of the quality and quantity of leachate is extremely important in the context of designing the leachate drainage system and landfill recycling system (Freyssinet et al., 2002). To check the impact of leachate on the soil and water environment, leaching tests (static and dynamic) and lysimeter tests are carried out (Maciejewski et al., 2006; Swati et al., 2011; Sołtysiak et al., 2017; Sołtysiak et al., 2018).

It is important to prevent the migration of pollutants to aquifers, but control of potential pollution is done by monitoring the groundwater (Slack et al., 2005; Nielsen eds. 2006). Water quality monitoring in landfills in Poland is imposed by the Polish Regulation of the Minister of Environment of April 30, 2013 (Journal of Laws, No. 523). Even though the most important contaminants of groundwater in the area of landfills are chlorides, sulphates, and ammonium ion, the regulation provides only for monitoring of EC, pH, TOC, Cu^{2+}, Zn^{2+}, Pb^{2+}, Hg^{2+}, Cd^{2+}, Cr^{6+} and PAHs (Talalaj and Biedka, 2016). Lots of publications focus only on heavy metals (Sakawi et al., 2011; Taha et al., 2011; Syahirah et al., 2013; Syafalni et al., 2014).

The simplest form of groundwater quality assessment is to classify the waters based on the Regulation of the Minister of Maritime Economy and Inland Navigation of October 11, 2019, on the criteria and method of assessing the status of groundwater bodies (Journal of Laws 2019, item 2148). It is also possible to analyse and forecast these changes using statistical methods based on trend analysis – linear model, Holt model, Winters model, etc. (Sun et al., 2020).

Based on the monitoring data, numerous methods have been developed to assess the vulnerability of groundwater to pollution and risk analysis (Boufekane and Saighi 2013; Singh et al., 2015; Bhuiyan et al., 2016; Hermanowski and Ignaszak, 2017). It should be noted that although the term ‘groundwater vulnerability to contamination’ has been operating since the 60s of the twentieth century (Witkowski and Kowalczyk, 2004), new methods of its assessment are still developing. Methods based on statistical methods (Dąbrowska et al., 2015), including artificial intelligence (Sołtysiak et al., 2016; Nourani et al., 2017a; Nourani et al., 2017b; Połap, 2018; Nourani et al., 2021), geostatistics (Panagopoulos et al., 2006; Dąbrowska et al., 2016), creating a vulnerability map (Witczak et al., 2007) as well as indicator methods (Backman et al., 1998; Gogu and Dassargues, 2000; Kabbour et al., 2006; Talalaj, 2014) are characterized by great popularity and complexity.

Unfortunately, not every method is applicable to every pollution sources due to the available data range. Many landfills are monitored only to the extent required by law. Machine learning methods require large amounts of data to make appropriate predictions, statistical methods require large amounts of parameters, parametric methods require a large amount of field work and laboratory determinations. In this context, indicator methods are the best, which can be used even when using data from the minimum monitoring scope (Kumar and Alappat, 2005).

One of the methods of mathematical description of groundwater vulnerability is the Backman contamination index (Backman et al., 2018). This index allows to specify the degree of groundwater pollution in relation to the value of natural hydrochemical background. In its original form, it included only the basic groundwater components, but can be extended to include calculations for other parameters.

The aim of this paper is to identify the changes in the physical and chemical parameters of groundwater because of values of the Backman index for three piezometers belonging to the monitoring network of the municipal landfill in Wojkowice (southern Poland) in 2013–2020. A novelty in the approach to the index formula is taking into account other components than the formula initially assumed. It is important because this procedure shows the greater impact of the landfill on groundwater in this area. Additionally, it is the first time that the groundwater pollutant vulnerability measure has been used for this area.

STUDY AREA

The landfill for non-hazardous and inert waste in Wojkowice is located in the northern part of the city, southern Poland (see: Fig. 1). In terms of physics and geography, the research area belongs to the macroregion of the Silesian Upland, the Hummock of Tarnowskie Góry mesoregion, which is the northern part of the

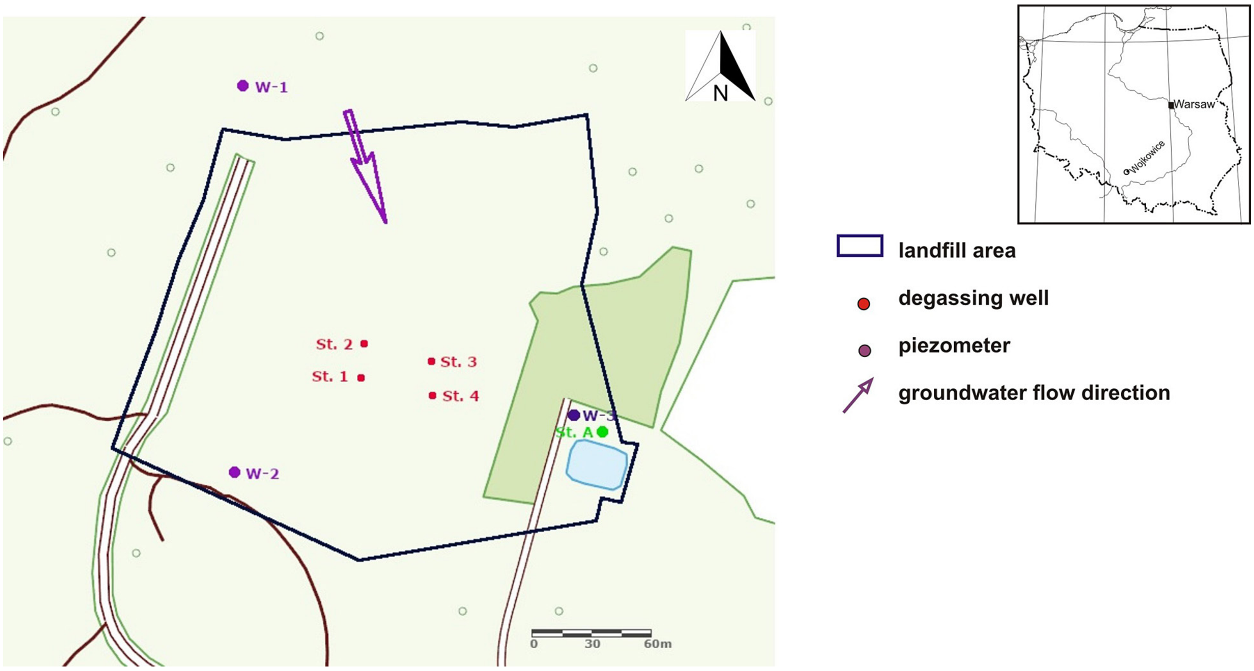


Fig. 1. Study area

Silesian Upland (Kondracki, 2009). There are no other groundwater pollution sources in the area of the landfill. The Quaternary and Tertiary formations take part in the geological structure of the area, below which there are Triassic and Carboniferous formations.

The Gogolin limestones, which build most of the hills around Wojkowice, were the subject of opencast mining for the cement industry. In the area described under the Quaternary formations, there are the formations of the rite and lower motley sandstone (Ciechanowska-Żurek, 2013). The formations of the Triassic carbonate series build dome-shaped hills with a tectonic-erosive genesis, separated from each other by clay outcrops of the lower mottled sandstone or by Carboniferous and Permian outcrops. The Quaternary is represented by the sediments of Pleistocene accumulation terraces. Lithologically, they are formed in the form of layers of clay and silty clay, gravel, and sand gravel as well as fine and dusty sands lying on the tertiary layers of clay. The thickness of the Quaternary in the area of the landfill ranges from 1.5 m to 12.5 m (Dindorf et al., 2005).

There are three aquifers in the area of the landfill in Wojkowice: Quaternary and two Triassic. The Quaternary aquifer is formed as sands with various grain sizes and degrees of slagging. Water in these rocks appears locally at the foot of the hills. The recharge of this layer is presumably carried out directly by precipitation, and the level is exposed to potential pollution sources (Dindorf et al., 2005). Two aquifers have been identified in the Triassic formations. The first layer is related to the calcareous-marly-dolomitic formations of the rite that occur in the western part of the area in question. The second layer is found in the shale of lower motley sandstone in the eastern part of the landfill (Dindorf et al., 2005).

The owner of the landfill is RECYKLING Wojkowice Ltd. The total capacity of the landfill is 262,700 m^3. The landfill is sealed with a natural geological barrier and an artificial geological barrier. The natural geological barrier is formed by the Lower Triassic formations with a thickness of 8 to 10 m. The hydraulic conductivity of these formations is 1×10^{-6} m/s. The artificial geological barrier is created using a bentomat waterproofing mat with a weight of 3000 g/m^2 with a hydraulic conductivity of 4.5×10^{-11} m/s. The bottom was lined with PEHD smooth foil and the slopes with 2 mm thick textured foil. The landfill also has a synthetic insulation in the form of 250 g/m^2 geotextile. The landfill also has leachate drainage through the seepage water drainage layer laid on the bottom in a coarse sand filtration layer with a thickness of 0.5 m and a hydraulic conductivity of 1 × 10^{-4} m/s. The groundwater monitoring network consists of 3 piezometers marked P1, P2, P3. The P1 piezometer is located at the water inflow to the landfill, and the P2 and P3 piezometers at the outflow. The waters in the P1 and P2 piezometers belong to the Triassic carbonate series complex, and from the P3 piezometer to the aquifer layer of the Świerklanieckie layers. Additionally, there are no other observation points.

METHODOLOGY

The C_d contamination index -Backman index (modified version of formula proposed by Hakanson (1980)) was used to evaluate the variability of temporal and spatial changes in chemical composition of groundwater in the region of the landfill in Wojkowice. This index shows the effect of diverse natural and anthropogenic environmental factors influencing quality of groundwater. The design of the indicator was proposed by Backman et al. (1998). The formula for calculating the index depends on the value of the hydrochemical background (Dragon, 2004).
The Backman index (C_d) is calculated from the formula (Backman et al., 1998; Bhuiyan et al., 2016):

$$C_d = \sum_{i=1}^{n} C_{fi} \qquad (1)$$

C_{fi} is the contamination index for the *i*-th component.

and

$$C_{fi} = \frac{C_{Ai}}{CNi} - 1 \qquad (2)$$

C_{Ai} is the analytical value for the i-th component.
C_{Ni} is the upper range of the hydrochemical background values.
n is number of components.

The contamination index was calculated on the basis of available data from the monitoring of the landfill from 2010-2020 i.e., specific electric conductivity (EC), pH, TOC, Cu^{2+}, Zn^{2+}, Pb^{2+}, Cd^{2+}, Cr^{6+}, and N-NO_3, N-NO_2 and N-NH_4. The results of monitoring tests from three piezometers (P1, P2, P3) were considered. It is worth noting that not all piezometers were tested in all years. The reason for this was the lack of water in the piezometer. If it is not possible to obtain the value of the natural hydrochemical background, the data from the piezometer located at the inflow of groundwater to the pollution sources area are considered.

The hydrochemical background was taken as the mean arithmetic values of particular concentrations of components from piezometer P1 located in the inflow of groundwater to the landfill region. These values were calculated from monitoring data in years 2010–2020. In the case of values that were below the limit of quantification, half of this limit was used for further calculations. The hydrochemical background calculated from the P1 piezometer data is dictated by the fact that no other data are available from the landfill area.

The contamination index was calculated using the following values of parameters (see: Table 1):

Table 1. Hydrochemical background values (Ciechanowska-Żurek, 2013)

Parameter	Value
EC (μS/cm)	601,34
pH –	7,3884
TOC (mg/dm^3)	2,0300
Cu (mg/dm^3)	0,0017
Zn (mg/dm^3)	0,0522
Pb (mg/dm^3)	0,0034
Cd (mg/dm^3)	0,0003
Cr (mg/dm^3)	0,0039
N-NO_3 (mg/dm^3)	2,9738
N-NO_2 (mg/dm^3)	0,0213
N-NH_4 (mg/dm^3)	0,1543

The particular interpretation of the values of index was presented in HONG-GUI ET AL., 2012. However, even values in the range of 1–2 suggest potential contamination.

RESULTS

On the basis of the groundwater monitoring results obtained in the area of the landfill in P1 piezometer, it can be concluded that all parameters indicate a good chemical status. Most of the values are in the I class of good chemical status. In the case of the P2 piezometer, all monitoring parameters are included in classes with a good chemical status, while the electrical conductivity already at this point is classified as II class of groundwater quality. In the case of the P3 piezometer, increased values of the electrical conductivity can be observed, which make the water of this piezometer classified into IV and V quality classes (see: Fig. 2A-D). Only the water from the piezometer P3 shows a poor chemical state. Among the parameters that show increased values, attention should be paid to total organic carbon, zinc, and lead. Changes in the content of these components are shown in Figure 2B-D. The values of total organic carbon in the P3 piezometer can be assigned to quality class IV or V. The zinc and lead content allows to classify water from the analyzed piezometers into quality class II or III.

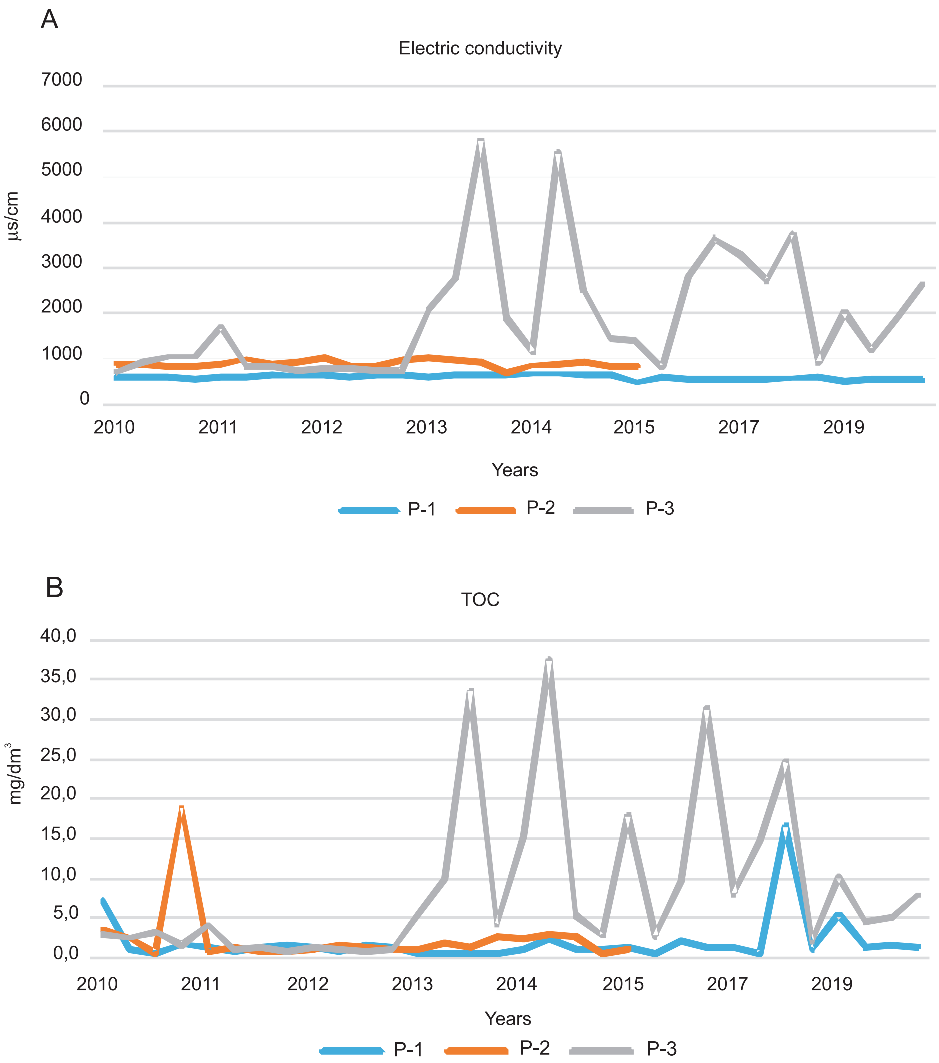
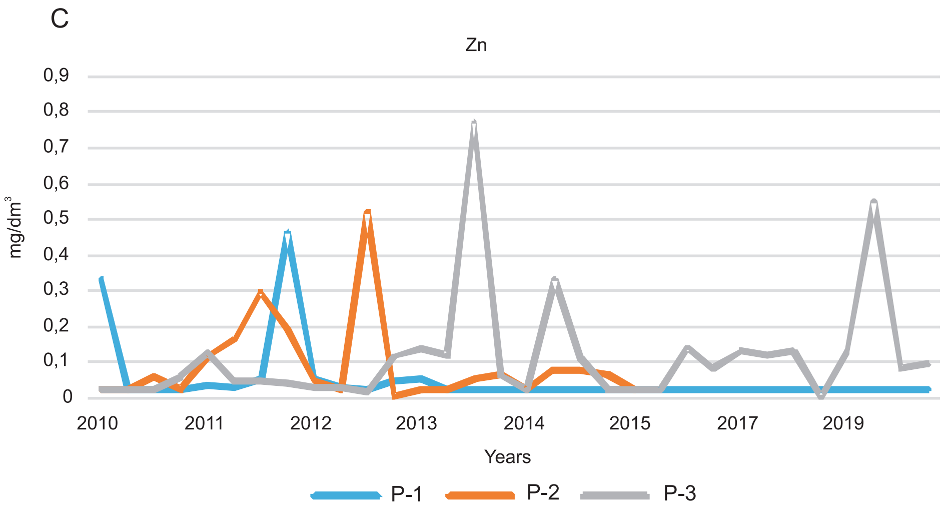


Fig. 2A–D. Changes of the selected parameters values



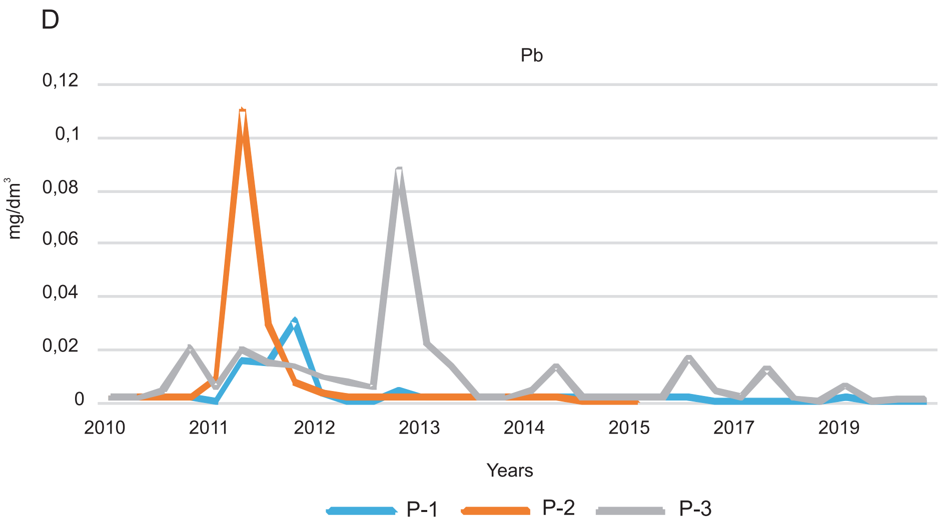


Fig. 2A–D cd. Changes of the selected parameters values

Basic statistics on selected parameters monitored in the waters of the described piezometers are summarized in Table 2.

The values of the neglect index for the analyzed period of research varied from -5.3 (P1) to about 603 (P3). The calculated values of the index indicate that the greatest pollution is concentrated in the area of the piezometer P3.

In the case of the P1 piezometer, for which the average values of individual parameters were used as hydrochemical background, the average value of this indicator was -0.3. The maximum value of the index for this piezometer was obtained in 2011 and was 19.5. The high concentration of lead, copper and zinc is responsible for the high value of the index for this piezometer.

For the P2 piezometer, the average pollution index was 5.04. The minimum value of this indicator was calculated for 2017 and amounted to –3.36. The highest value was obtained for 2012 and it was 38.56. This high value was mainly influenced by the lead and copper content. The share of lead pollution in the waters of this piezometer was about 81.3%.

In the case of the P3 piezometer, the average values of this indicator were approx. 66.8. The minimum

Table 2. Basic statistics

Piezometer	Parameter	Unit	Min value	Max value	Avg. value
P-1	pH	–	7	7.9	7.39
P-2	pH	–	6.8	7.32	7.03
P-3	pH	–	6.6	7.77	7.04
P-1	EC	µS/cm	487	670	601.34
P-2	EC	µS/cm	710	1043	898.23
P-3	EC	µS/cm	721	5790	1912.03
P-1	Pb	mg/dm^3	0.0005	0.031	0.0034
P-2	Pb	mg/dm^3	0.0005	0.11	0.009
P-3	Pb	mg/dm^3	0.0005	0.088	0.0098
P-1	Cd	mg/dm^3	0.00015	0.002	0.0003
P-2	Cd	mg/dm^3	0.000015	0.0005	0.0002
P-3	Cd	mg/dm^3	0.00015	0.002	0.0004
P-1	Cu	mg/dm^3	0.0005	0.011	0.0017
P-2	Cu	mg/dm^3	0.0005	0.021	0.0033
P-3	Cu	mg/dm^3	0.0005	0.032	0.0047
P-1	Zn	mg/dm^3	0.023	0.462	0.0522
P-2	Zn	mg/dm^3	0.0052	0.52	0.093
P-3	Zn	mg/dm^3	0.0025	0.77	0.1152
P-1	Cr	mg/dm^3	0.0005	0.005	0.0039
P-2	Cr	mg/dm^3	0.0005	0.005	0.0039
P-3	Cr	mg/dm^3	0.0005	0.005	0.0039
P-1	TOC	mg/dm^3	0.5	16.6	1.9344
P-2	TOC	mg/dm^3	0.5	18.9	2.4129
P-3	TOC	mg/dm^3	0.7	37.5	8.5781
P-1	$N\text{-}NO_3$	mg/dm^3	0.5	15.0961	2.495
P-2	$N\text{-}NO_3$	mg/dm^3	1.75	16.2914	6.7997
P-3	$N\text{-}NO_3$	mg/dm^3	0.22	1416.64	163.4246
P-1	$N\text{-}NO_2$	mg/dm^3	0.005	0.1314	0.0213
P-2	$N\text{-}NO_2$	mg/dm^3	0.005	0.0657	0.0207
P-3	$N\text{-}NO_2$	mg/dm^3	0.005	1.8068	0.1338
P-1	$N\text{-}NH_4$	mg/dm^3	0.0053	1.2365	0.1543
P-2	$N\text{-}NH_4$	mg/dm^3	0.0053	0.773	0.1885
P-3	$N\text{-}NH_4$	mg/dm^3	0.0167	3.5806	0.4884

value of the index for this point was –2.29 and was determined for 2012, while the highest, 603.63, was calculated for 2013. In the case of this piezometer, the high value of the index this year is determined by the content of nitrates, nitrites, and copper. The content of nitrates determined the value of the index in almost 79%. Several other high index values at this point were also influenced by the high copper content.

The reason for the increased values of the index in 2011 for P1 and P2 piezometers is not known. No incidents have been documented that could adversely affect groundwater quality in this area. Higher values of the index and the content of metals in waters are observed with a one-year delay in the case of the P3 piezometer. This is due to the time when pollutants migrate along the flow path. This phenomenon may be subject to further research.

Detailed index changes for all piezometers are shown in Figs. 3A-C.

The calculations of the pollution index indicate that the waters of piezometers located at the outflow of groundwater from the landfill area are under its influ-

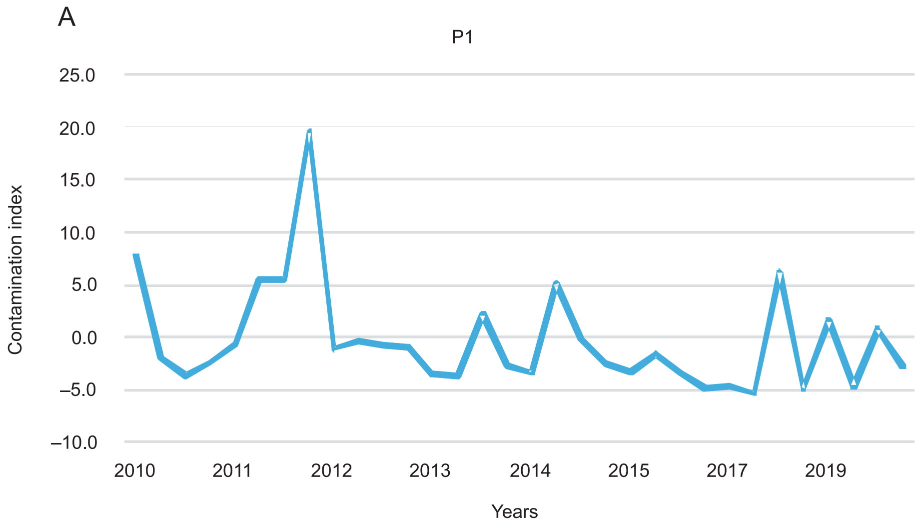


Fig. 3A. Changes of the contamination index values in piezometer P1

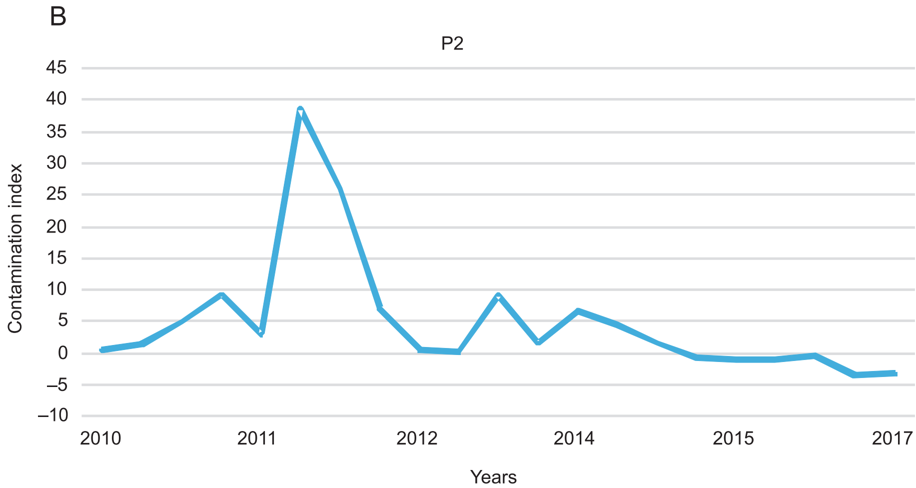


Fig. 3B. Changes of the contamination index values in piezometer P2

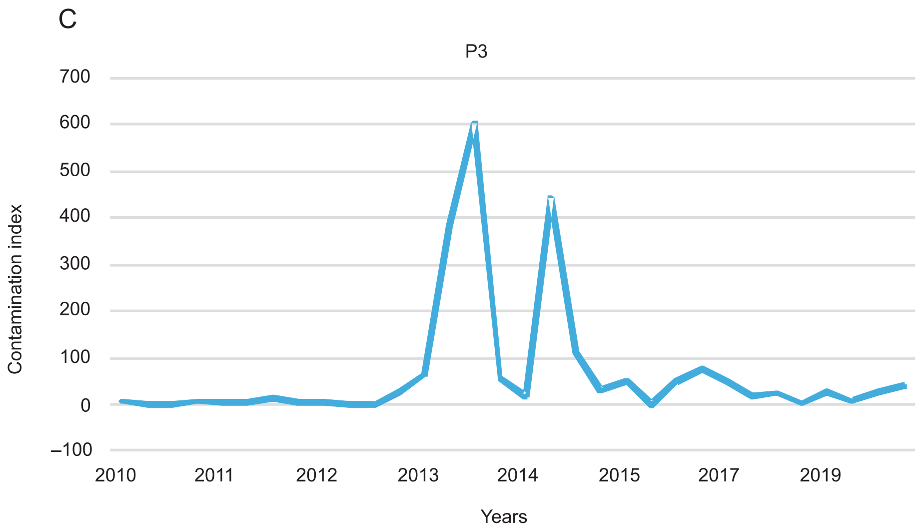


Fig. 3C. Changes of the contamination index values in piezometer P3

ence. This is especially evident in the P3 piezometer. The greatest fluctuations in the index values were observed for the P1 piezometer. The greatest differences in values were observed for the P3 piezometer.

Similar research was performed in the region of the landfill in Sosnowiec (southern Poland). The results of contamination index determined by the Backman method based on data from the monitoring of groundwater in 2014–2019 from the municipal landfill indicate high groundwater contamination in its area (Knopek and Dąbrowska, 2021). There, the C_d index was determined on the basis of the parameters that most exceed the criteria of the Regulation of the Minister of Maritime Economy and Inland Navigation of October 11, 2019, on the criteria and method of assessing the status of groundwater bodies, i.e., EC, SO_4^{2-}, Cl^-, Na^+ and Fe^{2+}. Various hydrochemical backgrounds were determined based on the monitoring of the landfill and the monitoring of the nearby Maczki-Bór sand mine. The average value of the index is 280.36. The highest value for background monitoring at the water inflow to the landfill is 19.79, the average value is 5.93, and the lowest is –3.21. Average values of the index for monitoring from the landfill were 33 times higher than for the water inflow to the landfill. The main parameters influencing the quality changes are sulphates and chlorides. Iron ions also have a high influence, but these may be of geogenic origin. The electrolytic conductivity of the EC had no significant effect on the index value.

Observing the changes in the value of this index in the waters of piezometers belonging to the observation network of the landfill in Wojkowice, it can be assumed that the quality of groundwater in this area is improving, and the values of this index show a downward trend.

CONCLUSIONS

Landfills, similarly, to waste incineration plants, composting plants, and sorting plants should be subject to groundwater monitoring. According to the current regulations, the scope of the monitoring performed is often too narrow. In addition to the traditional assessment of groundwater quality changes, mathematical indicators can be taken into account to determine the status of groundwater or its vulnerability to pollution.

An example of an indicator that can be used for this is Backman's pollution index. The choice of this indicator for the assessment of groundwater susceptibility to pollution is dictated by the fact that it is an objective measure in which the weights of individual parameters cannot be chosen freely. In the case of the described municipal waste landfill, the values of this indicator are over 600. Taking into account the fact that the value of the pollution index equal to 3 indicates a negative impact of the landfill on the quality of groundwater, it can be concluded that this facility affects groundwater. It is worth noting, however, that obtaining such a high value of the index is a single case. Among the available indicators for water quality assessment, the C_d pollution indicator deserves attention due to its applicability for various parameters, not only metals.

Studies (Backman et al., 1998) using the contamination index show that the water-quality parameters reflect the influence both of natural and anthropogenic environmental factors on groundwater quality. The authors of the latest research (Knopek and Dąbrowska, 2021) using this index state that the use of this measure to assess the vulnerability of groundwater to pollution is correct, although this indicator in compared to the Landfill Water Pollution Index is more sensitive to changes in the background value for described by them landfill. The authors of this article obtained the index value exceeding 1400.

When using this and similar measures to unambiguously assess the quality of groundwater and analyze these changes in the spatio-temporal system, not only single results should be considered, but also based on a large database. The results should be analyzed while also determining the position of the piezometer against the hydrodynamic system. It is also worth mentioning that this index can be used in further research to conduct a risk analysis for this area.

REFERENCES

Backman, B., Bodiš, D., Lahermo, P., Rapant, S., Tarvainen, T. (1998). Application of a groundwater contamination index in Finland and Slovakia. Environmental Geology, 36, 55–64.

Bhuiyan, M., Bodrud-Doza, M., Islam, A., Rakib, M., Rahman, M., Ramanthan, A. (2016). Assessment of groundwater quality of Lakshimpur district of Bangladesh using water quality indices, geostatistical methods, and multivariate analysis. Environmental Earth Sciences, 75(12), 10.1007/s12665-016-5823-y.

Boufekane, A., Saighi, O., (2013). Assessment of groundwater pollution by nitrates using intrinsic vulnerability methods: A case study of the Nil valley groundwater (Jijel, North-East Algeria). African Journal of Environmental Science and Technology, 7, 949–960.

Ciechanowska-Żurek, K. (2013). Monitoring of a landfill for non-hazardous and inert waste in Wojkowice – report for 2013 [in Polish]. SGS EKO-PROJEKT Ltd. Pszczyna.

Dąbrowska D., Kucharski R., Witkowski A. (2016). The representativity index of a simple monitoring network with regular theoretical shapes and its practical application for the existing groundwater monitoring network of the Tychy-Urbanowice landfills, Poland. Environmental Earth Sciences, 75, DOI: 10.1007/s12665-016-5554-0.

Dąbrowska, D., Sołtysiak, M., Biniecka, P., Michalska, J., Wasilkowski, D., Nowak, A., Nourani, V. (2019). Application of hydrogeological and biological research for the lysimeter experiment performance under simulated municipal landfill condition. Journal of Material Cycles and Waste Management, 21(3).

Dąbrowska, D., Sołtysiak, M., Waligóra, J. (2015). Short-term forecasting of the chloride content in the mineral waters of the Ustroń Health Resort using SARIMA and Holt-Winters models. Environmental & Socio-economic Studies, 3(4), 57–65.

Dąbrowska D., Witkowski A., Sołtysiak M. (2018A). Application of pollution indices for the assessment of the negative impact of a municipal landfill on groundwater (Tychy, southern Poland). Geological Quarterly, 62(3), 496–508.

Dąbrowska, D., Witkowski, A., Sołtysiak M. (2018B). Representativeness of the groundwater monitoring results in the context of its methodology. Environmental Earth Sciences, 77., DOI: 10.1007/s12665-018-7455-x.

Dindorf, L., Wojciechowska-Dindorf, W., Kalicki, R. (2005). Building-detailed design for “RECYKLING WOJKOWICE” Ltd. Extension of the existing landfill for non-hazardous and inert waste in Wojkowice, located on plots with registration numbers 2070/9 and 2070/23. INŻYNIERIA PRO EKO Ltd. Przedsiębiorstwo Inżynieryjno-Usługowe [in Polish] Warsaw.

Elbl, J., Vaverková, M., Adamcová, D., Plošek, L., Kintl, A., LošÁk, T., Hynšt, J., Kotovicová, J. (2015). Influence of Fertilization on Microbial Activities, Soil Hydrophobicity and Mineral Nitrogen Leaching, Ecological Chemistry and Engineering, 21(4), 661–675.

Freyssinet, P., Piantone, P., Azaroual, M., Itard, Y., Clozel--Leloup, B., Guyonnet, D., Baubron, J. (2002). Chemical changes and leachate mass balance of municipal solid waste bottom ash submitted to weathering. Waste Management 22(2), 159–172.

Gogu, R., Dassargues, A., (2000). Current trends and future challenges in groundwater vulnerability assessment using overlay and index methods. Environmental Geology, 39, 549–559.

Hakanson, L. (1980). Ecological Risk Index for Aquatic Pollution Control. A Sedimentological Approach, Water Research, 14, 975–1001.

Hermanowski, P., Ignaszak, T., (2017). Ground water vulnerability based on four different assessment methods and their quantitative comparison in a typical North European Lowland River catchment (the Pliszka River catchment, western Poland). Geological Quarterly, 61(1), 166–176.

Hussein, M., Yoneda, K., Mohd-Zaki, Z., Amir, A., Othman N. (2021). Heavy metals in leachate, impacted soils and natural soils of different landfills in Malaysia: An alarming threat. Chemosphere, 267.

Hong-gui, D., Teng-feng, G., Ming-hui, L., Xu, D. (2012). Comprehensive assessment model on heavy metal pollution in soil. International Journal Electrochemical Sciences, 7, 5286–5296.

Kabbour, B., Zouhri, L., Mainia, J., Colbeaux, J., (2006). Assessing groundwater contamination risk using the DASTI/IDRISI GIS method: coastal system of western Mamora, Morocco. Bulletin of Engineering Geology and Environment, 65, 463–470.

Knopek, T., Dąbrowska D. (2021). The Use of the Contamination Index and the LWPI Index to Assess the Quality of Groundwater in the Area of a Municipal Waste Landfill. Toxics, 9, 66. https://doi.org/10.3390/toxics9030066.

Kondracki, J. (2009). Regional geography of Poland [in polish]. PWN: Warsaw, 468.

Kumar, D., Alappat, B.J. (2005). Evaluating Leachate Contamination Potential of Landfill Sites Using Leachate Pollution Index. Clean Technologies and Environmental Policy, 7, 190–197.

Maciejewski S., Maloszewski P., Stumpp C., Klotz D. (2006). Modelling of water flow through typical Bavarian soils (Germany) based on lysimeter experiments: 1. Estimation of hydraulic characteristics of the unsaturated zone. Hydrological Sciences Journal, 51(2), 285–297.

Minelgaitė A., Liobikienė G. (2019). Waste problem in European Union and its influence on waste management behaviours. Science of The Total Environment, 667, 1, 86–93.

Mor S., Negi P., Ravindra K. (2018). Assessment of groundwater pollution by landfills in India using leachate pollution index and estimation of error. Environmental Nanotechnology, Monitoring & Management, 10, 467–476.

Nielsen, D.M.,ed., (2006). Practical handbook of environmental site characterization and ground-water monitoring. 2nd ed. CRC Press Taylor&Francis Group: 1318.

Nourani, V., Andalib G., Dąbrowska, D. (2017A). Conjunction of wavelet transform and SOM-mutual information data pre-processing approach for AI-based multi-Station nitrate modeling of watersheds. Journal of Hydrology, 548, 170–183.

Nourani, V., Foroumandi, E., Sharghi, E., Dąbrowska, D. (2021). Ecological-environmental quality estimation using remote sensing and combined artificial intelligence techniques. Journal of Hydroinformatics, 23(1), 47–65.

Nourani, V., Mousavi, S., Dabrowska, D., Sadikoglu, F. (2017B). Conjunction of radial basis function interpolator and artificial intelligence models for time-space modeling of contaminant transport in porous media. Journal of Hydrology, 548, 569–587.

Panagopoulos, G. Anatonakos, K., Lambrakis, N., (2006). Optimization of the DRASTIC method for groundwater vulnerability assessment via the use of simple statistical methods and GIS. Hydrogeology Journal, 14, 894–911.

Regulation of the Minister of Maritime Economy and Inland Navigation of October 11, 2019, on the criteria and method of assessing the status of groundwater bodies (Journal of Laws 2019, item 2148).

Regulation of the Minister of Environment of 30 April 2013. Regulation on landfills (Journal of Laws, No. 523)

Połap D. (2018). Human – machine interaction in intelligent technologies using the augmented reality. Information Technology and Control, 47, 4, 691–703.

Renou, S., Givaudan, J.G., Poulain, S., Dirassouyan, F., Moulin, P. (2008). Landfill leachate treatment: Review and opportunity. Journal of Hazardous Materials, 150, 468–493.

Rykała, W., Dąbrowska D. (2020). Risk assessment for groundwater in the region of municipal landfill systems in Tychy-Urbanowice (Southern Poland). Environmental & Socio-economic Studies, 8(1), 9–17.

Sakawi, Z., Mastura, S. a, Jaafar, O., Mahmud, M., Centre, E.O. (2011). Community perception of odor pollution from the landfill. GEOGRAFIA Online Malaysia Journal of Society and Space, 7(3), 18e23.

Singh, P., Verma, P., Tiwari, A., Sharma, S., Purty, P., (2015). Review of Various Contamination Index Approaches to Evaluate Groundwater Quality with Geographic Information System (GIS). International Journal of ChemTech Research, 7(4), 1920–1929.

Slack, R., Gronow, J., Voulvoulis, N. (2005). Household hazardous waste in municipal landfills: contaminants in leachate. Science of the total environment, 33, 119–137.

Sołtysiak, M., Dąbrowska, D. (2016). The smoothing methods used in assessing the influence of pollution sources on groundwater quality – a case study of metallurgical landfill in Lipówka (southern Poland). Environmental & Socio-economic Studies, 4(4), 61–67.

Sołtysiak, M., Blachnik, M., Dąbrowska, D. (2016). Machine- learning methods in the water reservoirs classification. Environmental & Socio-economic Studies, 4(2), 34–42.

Soltysiak, M., Dąbrowska, D., Żarski, T., Żyła, Ł., (2017). Lysimeter research of steel work slags from the Kato-

wice Steelwork (Southern Poland). SGEM 2017, Albena, 1, 513–520.
Soltysiak, M., Dąbrowska, D., Jałowiecki, K., Nourani, V. (2018). A multi-method approach to groundwater risk assessment: A case study of a landfill in southern Poland. Geological Quarterly, 62(2), 361–374.
Sun, Ch., Zhang, Ch., Li, F. (2020). A hybrid prediction model for residential electricity consumption using holt-winters and extreme learning machine. Applied energy, 275, 115383.
Swati, M., Karthikeyan, O., Joseph, K., Visvanathan, C., Nagendran, R. (2011). Pilot-scale simulation of landfill bioreactor and con-trolled dumping of fresh and partially stabilized municipal solid waste in a tropical developing country. J Hazard. Toxic, and Radioact. Waste, 15(4), 321–330.
Syafalni, S., Zawawi, M.H., Abustan, I. (2014). Isotopic and hydrochemistry fingerprinting of leachate migration in shallow groundwater at controlled and uncontrolled landfill sites. World Applied Sciences Journal, 31(6), 1198e1206.
Syahirah, Siti Nur, Mohd, A., Sumiani, Y., Yan Piaw, C. (2013). Soil chemistry and pollution study of a closed landfill site at Ampar Tenang. Waste Management. Resources, 31(6), 599e612.
Talalaj, I. (2014). Assessment of groundwater quality near the landfill site using the modified water quality index. Environmental Monitoring Assessment, 186(6), 3673–3683.
Talalaj, I., Biedka, P. (2016). Use of the Landfill Water Pollution Index (LWPI) for Groundwater Quality Assessment Near the Landfill Sites. Environmental science and pollution research, 23, 24601–24613.
Witczak, S., Duda, R., Żurek, A. (2007). The Polish concept of groundwater vulnerability mapping in: Groundwater Vulnerability Assessment and Mapping, International Association of Hydrogeologists Selected Papers, 11, 45–59.
Witkowski, A., Kowalczyk, A. (2004). A simplified method of regional groundwater vulnerability assessment. International Conference on Groundwater Vulnerability Assessment and Mapping, Ustroń, Poland.

OCENA ZMIAN JAKOŚCI WÓD PODZIEMNYCH W REJONIE SKŁADOWISKA KOMUNALNEGO W WOJKOWICACH

ABSTRAKT

Cel pracy
Składowanie to czynność, która może grozić zniszczeniem lub skażeniem środowiska gruntowo-wodnego. Zanieczyszczenia mogą być generowane zarówno przez odcieki, jak i przez gaz wysypiskowy. Uwarunkowania prawne nakładają na zarządców składowisk monitorowanie wód gruntowych na terenie składowisk. Gleby i wody podziemne wykazują wysokie stężenia chlorków, siarczanów i metali ciężkich, zwłaszcza w porównaniu z naturalnymi hydrochemicznymi wartościami tła. Wyniki monitoringu można analizować za pomocą wskaźników zanieczyszczenia. Celem pracy było określenie jakości wód podziemnych na składowisku odpadów komunalnych w Wojkowicach (południowa Polska) za pomocą wskaźnika Backmana.

Materiał i metody
Praca ma charakter nowatorski z uwagi na zastosowanie innego zakresu parametrów niż początkowo uwzględniał wzór do obliczenia tego wskaźnika. W artykule wzięto pod uwagę wyniki monitoringu jakości wody dla trzech piezometrów z lat 2013–2020. Wskaźnik zanieczyszczenia obliczono osobno dla każdej z analizowanych próbek wody, biorąc pod uwagę przewodnictwo elektrolityczne oraz stężenie całkowitego węgla organicznego (TOC), Cd, Pb, Zn, Cu, Cr oraz sumę N-NO3, N- NO2 i N-NH4.

Wyniki i wnioski
Zakres wartości wskaźnika Backmana w próbkach wód podziemnych wynosił od –5,3 do 603. Wartość wskaźnika Backmana rośnie wraz ze wzrostem stężenia poszczególnych parametrów w wodach podziemnych. W przypadku terenów silnie przekształconych wskaźnik zanieczyszczenia wód przyjmuje wartości wysokie, przekraczające 3. Wyniki tego wskaźnika wskazują, że jakość wód podziemnych wokół składowiska jest zła. W przyszłości można rozszerzyć uzyskane wartości wskaźnika o nowe parametry.

Słowa kluczowe: odpady, hydrogeologia, składowisko, wskaźnik Backmana, Wojkowice