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Original article

Groundwater quality testing in the area of municipal waste landfill sites in Dąbrowa Górnicza (southern Poland)

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ABSTRACT

Groundwater quality assessment for pollution can be undertaken with the use of indicators that will confirm or deny the negative impact of potential pollution sources. Based on water quality monitoring data from the Lipówka I and Lipówka II municipal landfill sites in Dąbrowa Górnicza from the last five years, the water quality in the area was assessed using the Nemerow Pollution Index (NPI) method. Seven parameters were assessed – pH, electrical conductivity, and the concentrations of chlorides, sulphates, ammonium ions, boron and iron. The limits for class III water quality were used as the reference level. The results of the NPI calculations show that the highest indices were obtained for the piezometers PZ5 and T5 located in the outflow of the water from the Lipówka I landfill site. The highest values of the Nemerow index were obtained for ammonium ions and reached a value of over 36 in the PZ5 piezometer and 17 in the T5 piezometer. The other parameters did not indicate a significant impact of the landfill sites on the quality of groundwater. The highest values of the indicators were observed in 2017. It is worth noting that, apart from the large differences in the content of ammonium ions, the values of the Nemerow indices for the electrical conductivity specifically for the PZ5 piezometer are twice as high as for the other piezometers and four times higher than for boron. The Nemerow index is a useful and easy method of assessing the quality of groundwater. It can even be used for a small number of parameters.

KEY WORDS: water quality, landfill sites, Nemerow index, municipal waste, Dąbrowa Górnicza

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1. Introduction

The increase in the production of municipal waste in the world (Yang et al., 2018) causes an increase in the need for storage of this waste (Dąbrowska & Rykała, 2021). Several methods are available for the disposal of waste, but the most popular procedure is burial in landfill sites. Once buried the waste undergoes different processes such as the mineralization of organic forms of nitrogen, sulphur, and phosphorus, and these cause the creation of new compounds (Sobik, 2007). Pollutants leach from waste and if these are not transferred to the leachate tank, they migrate into groundwater and negatively affect groundwater quality (Taylor et al., 2004). The best known contaminants deserve attention, these are: heavy metals, polycyclic aromatic hydrocarbons, steroids, and pesticides (Mohrling, 2007).

There is a need to conduct reliable groundwater monitoring studies in order to counteract the negative effects of pollution migration to groundwater (Dąbrowska et al., 2018; Gomo & Masemola, 2016). The protection of groundwater in the region of pollution sources also plays a key role in rational water management (Robins et al., 1998). The results of monitoring tests can be analyzed statistically, but they can also be used to calculate indicators which take into account selected physicochemical parameters. Groundwater quality assessment in the area of pollution hotspots should be both temporal and spatial. This means that the values of the indicators should be calculated for the entire observation network around the repository and extend over the largest possible period of time (NIELSEN, 2006).

There are lots of quality indices which can be used for the classification of water quality and can thus be indirectly used to assess the vulnerability of groundwater to pollution or environmental risk (PRITCHARD, 2013). The principal component analysis method or the fuzzy analysis methods (GAO & JIN, 2005; OUYANG, 2005) can also be used as complementary analyses to the calculation of the pollution indicators.

When selecting the parameters to be used to calculate the quality indicators, the risk of specific factors is identified (CHARTRES ET AL., 2019). The first water quality indicators appeared in the mid-1800s (ABBASI & ABASSI, 2012). The most popular measure of water quality assessment is the Water Quality Index (WQI) and its modifications (DEBELS ET AL., 2005; KANNEL ET AL., 2007; LOWE ET AL., 2017; SUN ET AL., 2016). Since the creation of the first index by Horton, more than 35 modifications have been developed, which are currently used in the assessment of the quality of surface and groundwater. Each model of the WQI involves a few calculation steps, including selection of the water quality parameters, generation of the parameter sub-indices, determination of the parameter weight values and calculating the index (LUMBET AL., 2011). Different pollution indices are very effective tools to analyze monitoring data and are helpful to the public and to decision makers (CAEIRO ET. AL., 2005; WU ET AL., 2018).

Other examples of indicators that use different physicochemical parameters are the Backman index (BACKMAN ET AL., 1998; KARKOCHA, 2021; KNOPEK & DĄBROWSKA, 2021) or a modified version of the WQI - Landfill Water Pollution Index (TALALAJ, 2014). Another example of the index is the Nemerow Water Quality Index method (NWQI) which was created by Nemerow and Sumitomo in the 1970s (NEMEROW, 1974). It is worth noting that this method was also used for surface water quality evaluation in China by China's environmental protection department (ZHANG, 2017). An important advantage of this indicator over others is that it does not require weights of individual parameters, and each parameter can be considered separately.

In this article calculations of the Nemerow Water Quality Index were performed for groundwater quality assessment in the region of Lipówka I and Lipówka II municipal landfill sites in Dąbrowa Górnicza (southern Poland). The aim of the study was to investigate the patterns of the Nemerow Index and to determine the highest water pollution based on the results of monitoring from the observation network of these landfill sites between the years 2016-2020.

2. Study area

The system of municipal landfill sites Lipówka I and Lipówka II is located in the south-eastern part of Dąbrowa Górnicza in the Strzemieszyce Małe district (southern Poland; Fig. 1). The Lipówka I landfill site was established in 1992, and the Lipówka II landfill site in 2005. The following types of waste are brought to the municipal landfill (39,200 Mg/year): biodegradable kitchen waste, green waste, paper and cardboard, multi-material packaging, plastics, glass, metals, clothing, textiles, wood, hazardous waste, bulky waste, waste electrical and electronic equipment and renovation and construction waste. Waste is segregated mechanically and manually.

Both landfill sites are equipped with a leachate drainage system and a liner system. The liner system for the Lipówka I landfill consists of the following elements: native soil, a layer of sand (drainage under the seal) – 15 cm thick, blast furnace slag – 27 cm thick, asphalt concrete, medium-grained, with a partially closed structure – thickness 4.0 cm, fine-grained asphalt concrete, with a closed structure – gr. 4.0 cm and asphalt. The seepage water reservoir – made of reinforced concrete has two chambers with dimensions of 24 x 6 m and a usable depth of about 7.0 m, completely embedded in the ground. Rainwater percolating through the landfill, seeps through the waste and is captured by a system of drainage pipes placed on the bottom in a gravel filtration layer. The sewage by gravity is discharged through a pipeline to the collecting well through the gate valve chamber, from where, using a pump and a discharge pipeline, it is transferred to a two-chamber retention tank and then transferred to the treatment plant. Under the sealed bottom of the landfill basin, a drainage system was made to collect groundwater. The groundwater is collected within a system of PVC drainage pipes and discharged by gravity to the drainage water reservoir, where it is temporarily stored for firefighting purposes of waste, sprinkling the waste deposit and watering greenery in the reclamation process. The excess water is discharged as overflow to the rainwater drainage system.

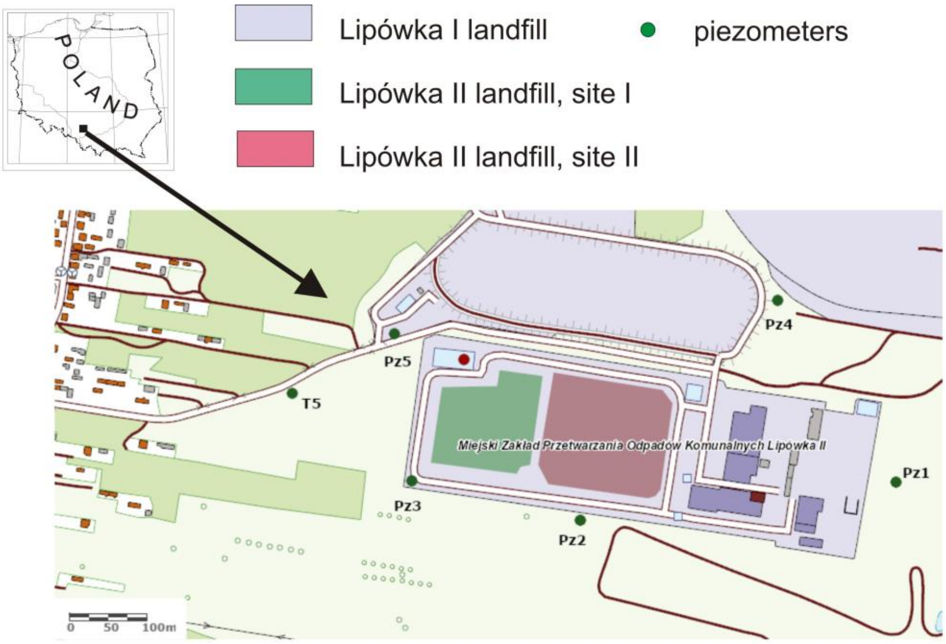

Fig. 1. Study area

In the case of the Lipówka II landfill, the liner system consists of the following elements: a bentonite mat with a basis weight of 5000 g/m^2 and a hydraulic conductivity value $k < 5 \cdot 10^{-11}$ m/s, a PEHD geomembrane with a thickness of 2.0 mm, geotextile > 800 g/m^2 and a 10-15 cm thick barrier composed of a single layer of cohesive soil. The leachate drainage system includes a drainage layer – 0.5 m with a hydraulic conductivity of 10^{-3} m/s. Collective pipelines are made of PEHD material with a diameter of 176 mm/150 mm. The leachate is collected in a 2300 m^3 tank and excess leachate is sent to the treatment plant.

The municipal landfill of Lipówka II is equipped with a groundwater monitoring system represented by piezometers PZ1, PZ2, PZ3, PZ4 and PZ5 (Fig. 1), the last two of which also monitor the groundwater in the region of the Lipówka I landfill. Piezometers are located about 25 meters deep. The water table is located at a depth of about 20 meters. The filter zone is located approx. 1 m below the water table.

3. Geological and hydrogeological conditions

Both landfill sites are located in the north-eastern part of the Upper Silesian Coal Basin (Stupnicka, 2007). The most important part of the geological profile of the study area are the Triassic and Quaternary formations. The Triassic sediments are represented by formations of lower and middle Buntsandstein, Roet, and locally of Muschelkalk. The Buntsandsteins are represented by conglomerates, sands, sandstones, siltstones and claystones. Roet formations are dolomitic marl, marl dolomites and marl limestone. The upper part of the Roet consists of bedded dolomites and limestones (Alexandrowicz & Alexandrowicz, 1960). Muschelkalk is connected with carbonate formations. The Quaternary deposits occur in the depressions of the terrain lying on the Triassic carbonate formations and are built from silt, clay and sand. In this region glacial tills of the South Polish Glaciation were found (Cabała & Cabała, 2004).

In the area of the municipal landfill sites, there are two water-bearing layers: Quaternary and Triassic aquifers. The Quaternary layer is characterized by a variable thickness and a lack of continuity. It is associated with fluvioglacial sands with a thickness < 6 m. The general direction of the groundwater flow in this aquifer is southerly. This aquifer is directly recharged with infiltrating water. The hydraulic conductivity is about $7.1 \cdot 10^{-6}$ m/s. The groundwater tables are either unconfined or locally confined (Sołtysiak et al., 2018). The Triassic aquifer is connected with dolomites and limestones. The main aquifer is of the Roet type. The thickness of this unconfined aquifer is up to 20 m, while the hydraulic conductivity is about $1.57 \cdot 10^{-4}$ m/s.

4. Methodology

Samples were analyzed following the standard methods for examination of water bodies on the basis of Regulation of the Minister of Maritime Economy and Inland Navigation of October 11, 2019 on the criteria and method of assessing the state of groundwater bodies (Journal of Laws 2019 item 2148). As the values to which the monitoring results were compared, the limits for class III water quality were adopted, which correspond to the good status of groundwater. The parameters analyzed were pH, electric conductivity, chlorides, sulphates, ammonium ion, boron and iron. The results are of chemical analyzes for piezometers belonging to the observation networks around the described municipal waste landfills from the years 2016-2020.

The Nemerow Pollution Index (NPI) is one of the most popular methods which can be used to evaluate the status of water quality (Zhang et al., 2018). It is calculated on the basis of the following formula:

$$NPI = \frac{C_i}{L_i},$$

where:

C_i – is the measured value of the i^{th} parameter

L_i – is the allowable limit of the i^{th} parameter

When the values of the indicators for individual parameters are lower than or equal to 1, it means that the water is within the acceptable range for class III water quality and there is no visible impact of the landfill. The limit values were: 2500 µS/cm for conductivity, 250 mg/l for chlorides and sulphates, 1.5 mg/l for ammonium, 1 mg/l for boron and 5 mg/l for iron. In the case of pH, it was checked that the measured value was in the range of 6.5-9.5. The higher the value of the index for individual parameters, the more negative the impact of the landfill on the quality of the groundwater. Piezometers PZ1, PZ2, PZ3 and T5 were tested quarterly, and piezometers PZ4 and PZ5 once every six months.

5. Results and discussion

The values of the Nemerow index were calculated based on data from piezometers capturing the Triassic aquifer (Table 1). The water from the Triassic aquifer was classified as weakly alkaline. The maximum pH value (8.2) was found in the T5 piezometer. All pH values recorded in the monitoring network in the analyzed period of time met the range for quality class III. The numerical value of the Nemerow index was not calculated for this parameter. The lowest pH values were recorded in the PZ2 piezometer, and the highest in the T5 piezometer. The greatest differences were found in the T5 piezometer. Similar trends of changes also occurred in this piezometer and PZ3 (Fig 2A).

The average value of the specific electrolytic conductivity for most piezometers did not exceed 1000 µS/cm. Much higher values, reaching over 2000 µS/cm, were recorded in the PZ5 piezometer. Over time, the electrical conductivity remains constant at almost all points. The smallest differentiation can be observed in the waters of the PZ4 piezometer. The greatest fluctuations occur in the case of the PZ5 piezometer. It should be noted that similar trends in changes occur for the piezometers PZ3 and T5, additionally a similar trend, but the shift occurs for piezometer PZ1. Based on these incomplete results, it is also possible to find similar changes in the EC values for water in the PZ4 and PZ5 piezometers (Fig. 3).

Table 1. Nemerow Pollution Index values

Piezometer	Parameter	Max NPI	Min NPI	Avg NPI
PZ1	pH	-	-	-
	Conductivity	0.350	0.252	0.313
	NH_4	1.467	0.087	0.282
	Cl	0.060	0.012	0.033
	SO_4	0.172	0.056	0.123
	B	0.096	0.005	0.033
	Fe	0.022	0.003	0.010
PZ2	pH	-	-	-
	Conductivity	0.398	0.330	0.367
	NH_4	0.8	0.18	0.315
	Cl	0.464	0.208	0.300
	SO_4	0.5	0.296	0.409
	B	0.195	0.005	0.093
	Fe	0.033	0.0032	0.017
PZ3	pH	-	-	-
	Conductivity	0.348	0.212	0.304
	NH_4	1.333	0.087	0.219
	Cl	0.2	0.026	0.125
	SO_4	0.496	0.152	0.355
	B	0.6	0.033	0.114
	Fe	0.017	0.001	0.007
PZ4	pH	-	-	-
	Conductivity	0.424	0.324	0.347
	NH_4	19	0.087	9.365
	Cl	0.720	0.208	0.365
	SO_4	0.720	0.440	0.614
	B	0.220	0.005	0.070
	Fe	0.002	0.006	0.013
PZ5	pH	-	-	-
	Conductivity	0.808	0.269	0.648
	NH_4	36.133	3.867	11.544
	Cl	1.280	0.092	0.951
	SO_4	1.320	0.030	0.941
	B	0.980	0.024	0.498
	Fe	0.019	0.002	0.010
T5	pH	-	-	-
	Conductivity	0.320	0.238	0.277
	NH_4	17.400	2.200	8.639
	Cl	0.800	0.076	0.221
	SO_4	0.800	0.016	0.206
	B	0.428	0.005	0.0956
	Fe	1.638	0.001	0.089

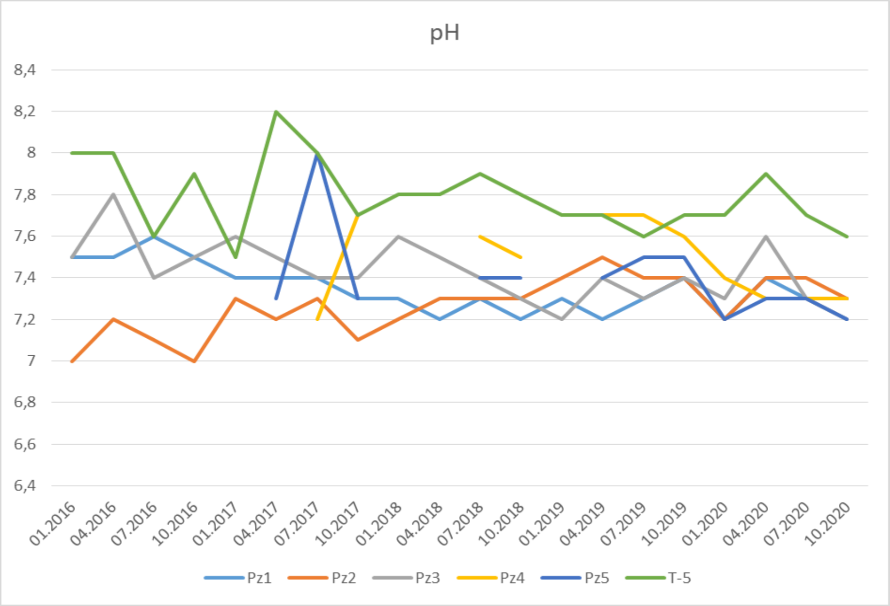

Fig. 2. Changes in pH values

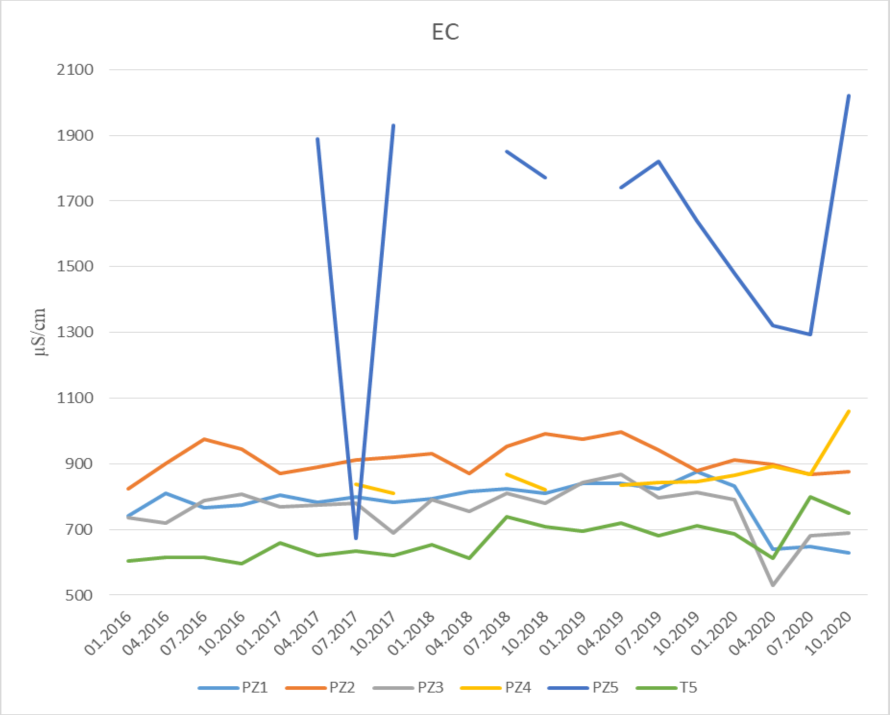

Fig. 3. Changes in EC values

Groundwater in this region is characterized by a high content of nitrogen compounds, with particular emphasis on the ammonium ion (Fig. 4). In the case of the PZ5 piezometer, the concentration of this ion was close to 55 mg/l. This may prove the existence of reducing conditions. In the case of this piezometer, the NPI value for ammonium ions exceeded 36. The lowest ammonium ion values were observed in the waters of the PZ2 piezometer. The calculated NPI value for this piezometer did not exceed 1 for any of the measurements.

In the piezometers PZ1, PZ2 and PZ3, there are no significant differences in the content of this ion throughout the entire research period. On the other hand, large fluctuations can be seen in the remaining three points. A significant increase in the concentration of this ion took place in 2017.

Chlorides are a characteristic parameter for waters in the area of municipal landfill sites. Significantly high values for this parameter, from 150 to 320 mg/l, were found in piezometers PZ4, PZ5, T5 (Fig. 5). The highest NPI values for this piezometer were calculated for the PZ5 and T5 piezometers.

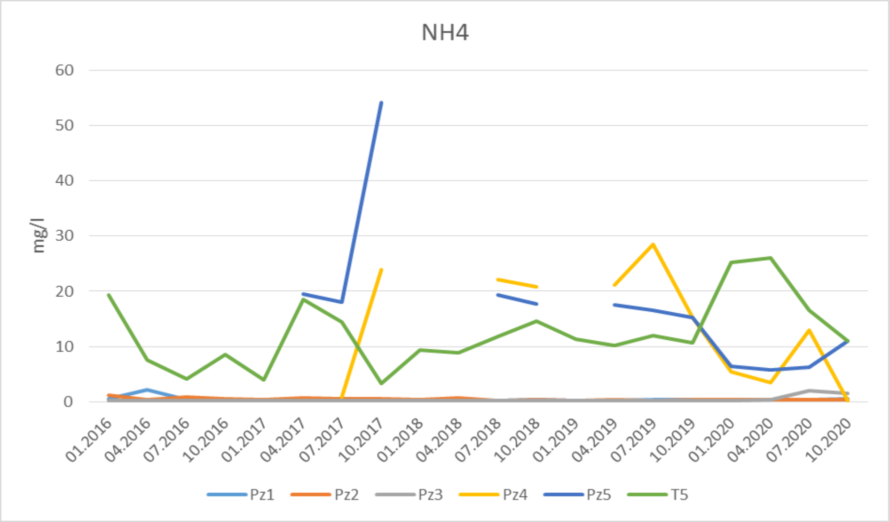

Fig. 4. Changes in NH_4^+ values

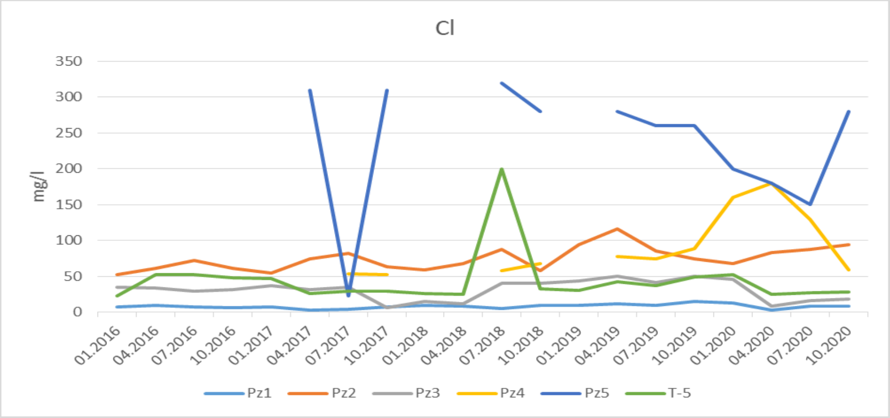

Fig. 5. Changes in Cl^- values

Chloride content throughout the research period remained at a similar level in piezometers PZ1, PZ3 and T5. In the case of the PZ5 piezometer, a very large variation in the content of this parameter can be noticed even within one year.

The content of sulphates in the entire research period was lowest in the T5 and PZ1 piezometers. Higher values (approx. 100 mg/l) were observed in the PZ2 and PZ3 piezometers. The highest concentrations were recorded in the PZ4 and PZ5 piezometers. As in the case of chlorides, a decrease in the content of sulphates in the waters of the PZ5 piezometer was recorded in 2017 (Fig. 6).

As in the case of chlorides, significantly higher values of sulphate content were recorded in the PZ4, PZ5 and T5 piezometers. These were also values of up to 300 mg/l. NPI values for this parameter exceeding 1 were calculated for the PZ5 piezometer.

Another example of an indicator of groundwater pollution in the area of municipal landfill is boron. In the case of PZ3, PZ5 and T5 piezometers, the Nemerow index values exceeded 0.5. In the case of the PZ5 piezometer, this value is close to 1. Note that the upper limit of the presence of this element in water is 0.1 mg/l. Boron content was low in piezometers PZ1, PZ4, T5. Significant changes in the content were recorded in the PZ3 and PZ5 piezometers (Fig. 7).

The maximum concentration of iron, and thus the NPI index, was found in the T5 piezometer. Increased concentrations of this component also indicate the presence of reducing conditions. In the case of iron, much higher values were observed in the T5 piezometer between 2016-2018 (Fig. 8). After this period, the content of this ion came closer to the values observed in the remaining piezometers of the network.

This research aimed to analyze the hydrogeochemical variations of the NPI index values in relation to the study area located in Dąbrowa Górnicza. The analysis of the values for the index highlighted that most of them do not show significant differences in relation to the third class of water quality. Typical rates of groundwater pollution in the area of this landfill site are significantly lower than for other facilities of this type (Aljaradin & Persson, 2016; Dąbrowska et al., 2018; Sarto et al., 2016).

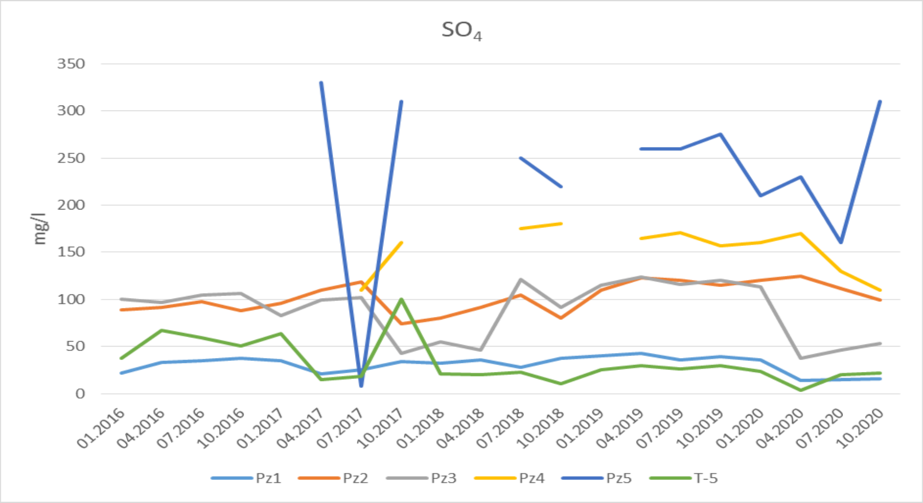

Fig. 6. Changes in SO_4^{2-} values

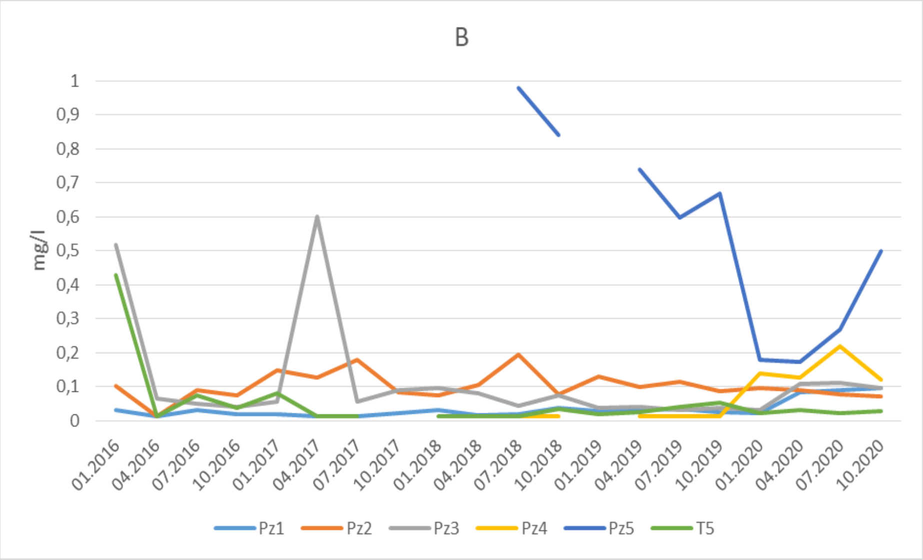

Fig. 7. Changes in B values

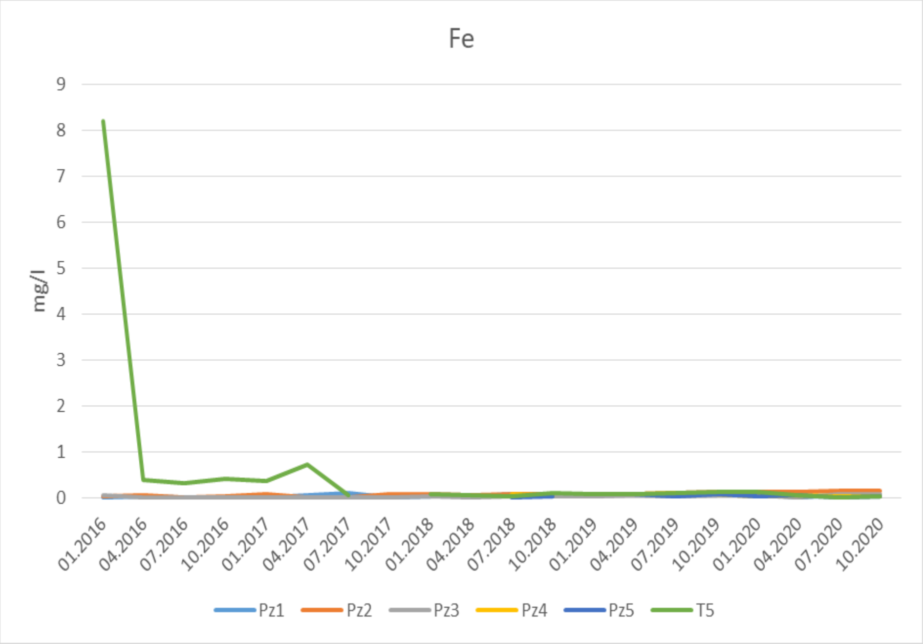

Fig. 8. Changes in Fe values

Increased pH values and increased alkalinity of groundwater are not conducive to the dissolution of metals in water, which is also noticeable in the results concerning the concentrations of metals in the water. Among metals, the highest concentrations are seen only in the case of iron ions. Other metals recommended for observation (Zn, Cu, Pb, Cd, Hg, Cr) are present in the waters of these piezometers and tested below the quantification limit, with the exception of mercury. The pH values in the waters of the analyzed piezometers are comparable to other landfills such as those described by RAHIM ET AL. (2010) or BRENNAN ET AL. (2016).

The value of the electrical conductivity in groundwater in the vicinity of landfill sites may be different and dependent on the hydrogeological conditions and the extent of the landfill's impact on the water. In the case of the described facility, the conductivity exceeds the value of 2000 µS/cm, but it is low compared to facilities such as the landfill site in Sosnowiec (KNOPEK & DĄBROWSKA, 2021) where the conductivity was twice as high, or the landfill site in Tychy (DĄBROWSKA ET AL., 2018) where the conductivity in one piezometer exceeded 20,000 µS/cm.

Chemical parameters such as ammonium, chlorides, sulphates, iron and boron occur in groundwater in the area of this landfill at the level described in the area of this type of facility (BHUIYAN ET AL., 2016; BOJAKOWSKA, 1994; NIELSEN, 2006; SINGH ET AL., 2015). The monitoring of landfill sites, which strongly affect the quality of groundwater, indicates that the chloride content in the waters may reach a value of 5000 mg/l, and the ammonium ion content may exceed a value of 120 mg/l (WITKOWSKI & ŻUREK, 2007).

When observing changes in the value of the Nemerow index in the waters of piezometers belonging to the observation network of the landfill sites, it can be assumed that the quality of groundwater in this area is varied. By far the poorest quality of water occurs in the case of the PZ5 piezometer. Due to the relatively short observation period, it is difficult to determine the trend of changes in individual parameters. The use of the Nemerow index to interpret groundwater quality is helpful as it allows the overall degree of pollution to be determined with a single measure. Additionally, the concentrations of individual elements can be related to the background value, or this index can be used for comparison purposes with other methods (indices).

6. Conclusions

The NPI is a useful measure for assessing the quality of groundwater and for determining the impact of pollution outbreaks on the condition of the water. An important issue when choosing this indicator for the analysis of water quality for a given region is also the choice of parameters that are to be used for characterization. For the Lipówka I and Lipówka II municipal waste landfill sites, a set of optimal parameters was selected, which are characteristic for the majority of facilities of this type.

The second aspect that should be taken into account is the value to which the measured concentration of the parameter is related. In this study, the values proposed in the regulation were used, but the natural hydrochemical background values can also be used, if available.

If the recorded values of individual parameters were compared to the natural hydrochemical background for this region (RÓŻKOWSKA ET AL., 1975), which for example was 33 mg/l in the case of chlorides, the values of the Nemerow index would often exceed the value of 100.

In the case of an area where there are also other landfill sites, the specific parameters contaminating the groundwater should also be taken into account. However, such data for the described landfill sites are not available.

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