Acta Geographica Silesiana, 17. WNoZ UŚ, Sosnowiec, 2014
s. 11–15

Dominika Dąbrowska, Marek Sołtysiak

University of Silesia, Faculty of Earth Sciences, Będzińska 60, 41-200 Sosnowiec; e-mail: ddabrowska@us.edu.pl, soltysiak.marek@gmail.com

MATHEMATICAL ASSESSING OF THE GROUNDWATER QUALITY: A CASE STUDY FROM LIPÓWKA LANDFILL

Dąbrowska D., Sołtysiak M. **Matematyczna ocena jakości wód podziemnych (na przykładzie składowiska Lipówka).** Dokonano oceny jakości wód podziemnych w rejonie zespołu składowisk w Strzemieszycach. Pod uwagę wzięto zawartość chlorków. Celem pracy było wyznaczenie zmian jakości wód podziemnych przy użyciu statystycznej metody średnich ruchomych.

W obliczeniach wzięto pod uwagę wyniki analiz chemicznych zawartości chlorków dla okresu 21 lat w dwóch piezometrach składowiska dawnej Huty Katowice. Dane te pozwoliły wyznaczyć trendy zmian jakości wód podziemnych w czwartorzędowym i triasowym piętrze wodonośnym na badanym obszarze. Wyniki obliczeń wskazują na negatywny wpływ składowiska na jakość wód podziemnych.

Домбровска Д., Солтысяк М. **Математическая оценка качества подземных вод (на примере свалки Липувка).** Сделана оценка качества подземных вод по соседству с комплексом свалок отходов в г. Домброва Гурнича Стшемешице с учетом содержания хлоридов. Цель статьи – определить изменения качества подземных вод при помощи статистического метода средних бегущих.

В расчетах принимались во внимание результаты химических анализов содержания хлоридов за период 1991–2012 гг. в двух пьезометрах свалки бывшего металлзавода Гута Катовице. Данные результаты позволили выявить тенденции изменений качества подземных вод в пределах четвертичного и триассового водоносных горизонтов данной территории. Исследования свидетельствуют о отрицательном влиянии свалки на качество подземных вод.

Key words: landfills, groundwater quality, assessing trends
Słowa kluczowe: składowiska odpadów, jakość wody gruntowej, ocena trendów
Ключевые слова: свалки отходов, качество грунтовой воды, оценка тенденций

Abstract

Groundwater quality study in the context of chlorides was carried out in the system of landfills in Strzemieszyce. The objective of this study is to identify changes of the quality of groundwater using the method of ordinary 3-periods moving averages.

Chlorides are a very good indicator of contamination in groundwater. Groundwater-quality data from a sampling of 2 piezometers from 21 years were analyzed. The data from these two monitoring points allowed us to determine trends of hydrogeochemical elements of groundwater from Quaternary and Triassic aquifer in this region.

The use of mathematical methods in determining trends in water quality has improved the influence of metallurgical landfill in Strzemieszyce on groundwater quality.

INTRODUCTION

Old landfills can be a really threat to groundwater quality (SITEK et. al., 2010). They were built directly on land without any sealing system. The major problem connected with this construction is losing of the leachates. Modern landfills have lining systems e.g. from geomembrane or HDPE.

One of the methods to protect aquifers before contamination from the really pollution sources is control functioning of these sources and groundwater monitoring. Groundwater monitoring is conducted in compliance with the *Regulation of the Minister of Environment of 30 April 2013 on the landfill of waste (OJ dated 2 May 2013 Pos. 523)*. This regulation requires drilling at least one borehole in the groundwater inflow and two points in the outflow through the landfill. Moreover on waste land in the case of exploited landfills sampling is made every quarter and in the case of non-exploited landfills every half year and samples are subjected to physical and chemical analyses. All reliable results of chemical analyzes are subjected to statistical analysis. It can be used to predict changes in the groundwater quality and to prevent deterioration of their condition. This paper presents an overview of the moving average method in the research on assessing trends in groundwater quality. We focused on the data from metallurgical landfill Lipówka in Dąbrowa Górnicza.

GENERAL CHARACTERISTICS OF THE STUDY AREA

The landfill of the steel industry waste in the district of Dąbrowa Górnicza – Strzemieszyce was found in 1985. It covers an area of over 45 hectares (Fig. 1). It was using by Huta Katowice (now Arcelor Mittal).

It is old landfill without any protection from the ground. In 2004, the total amount of waste deposited was 7.9 million tonnes. The landfill is in the form of the block above the ground, with a maximum thickness of more than 30 m of deposited waste. The dominant type of waste is in approximately 70% metallurgical slag and in 15% dust from the thermal- electric power station. Until the early 90's it has been stored even 1500 thousand tons of waste per year. At present we observe a downward trend in volume of waste deposited.

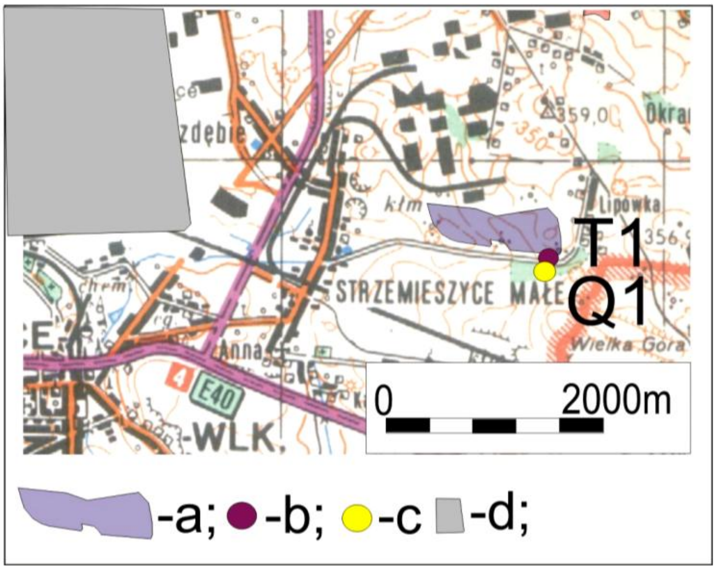

Fig. 1. Location of the landfill Lipówka in Strzemieszyce:
a – the landfill of the metallurgicalslag, b – the piezometer T1, c – the piezometer Q1, d – ironworks ArcellorMittal Poland
Rys. 1. Położenie składowiska Lipówka w Strzemieszycach:
a – składowisko odpadów przemysłowych, b – piezometr T1, c – piezometr Q1, d – huta ArcelorMittal

The metallurgical landfill Lipówka is located in the zone of Triassic tracks outcrops, shaped as marls and dolomites. These sediments form the recharge zone of Main Groundwater Reservoir 454 Olkusz–Zawiercie. There are Quaternary deposits over the Triassic formations in the eastern part of the landfill. There the aquifer with the surface of the groundwater is located at a depth of about 5–6.5 m below the ground (DĄBROWSKA, SOŁTYSIAK, in press).

Landfill Lipówka is one of several landfills located in Strzemieszyce. Monitoring network for this landfill consists of 16 piezometers (SOŁTYSIAK, 2007). Six of them monitoring Quaternary aquifer. There are piezometers Q1 (Quaternary aquifer) and T1 (Triassic aquifer) next to the landfill within the valley of Zakawie.

The chemical analysis for different pollution sources include steel industry waste are characterized by the following indicators of water pollution: increased mineralization, elevated concentrations of sulphate, chloride, calcium, magnesium, and arsenic, mercury, cyanide, cadmium, copper, chromium, lead, selenium, zinc, iron, manganese, barium, strontium, nickel, beryllium, magnesium, oil, grease and phenols (BARAN, TURSKI, 1995; MACIOSZCZYK, DOBRZYŃSKI, 2002). In this paper we focused on changes of chlorides` concentration. Groundwater monitoring database has covered chemical analysis results since 1989. We have used only reliable and representative data.

METHODOLOGY

The determination of trends in water quality requires the identification of the initial chemical composition of groundwater. The assessment the transformation degree of the chemical composition of groundwater is connected with determining the hydrochemical background. It is established for a given environment, hydrogeological unit (or part of it) the extent of the occurrence of an element or group of hydrochemical elements (MACIOSZCZYK, 1987). Depending on the occurrence of groundwater (main features), it can be determined natural hydrochemical background or in the case of the study area covered by anthropogenic influences, current hydrochemical background (KMIECIK, SZCZEPAŃSKA, 2005).

There are two groups of methods of determining the hydrochemical background – graphical or statistical. Using each of them requires the suitable distribution (MACIOSZCZYK, DOBRZYŃSKI, 2002). Graphical methods can be used both for distributions with many vertices and one vertex. The hydrochemical background is preceded by a determination and analysis of the trend of changes in water quality. Determining the trend (smoothing time series) is made by analytical and mechanical methods. Second method is much easier and it is based on the elimination of a random variation by converting linear time series.

The best method for smoothing time series is a period moving average (arithmetic mean of the number of consecutive elements). Choosing more averaged terms of the series results in a greater smoothing of the trend line. The length of the moving average can be chosen so that seasonal changes in the concentration of the test will be completely suppressed (KOT, JAKUBOWSKI, SOKOŁOWSKI, 2007).

It is possible to use different period moving average and it is worth mentioning that this method allows to forecast the value of content without taking into account the random factors.

We used this method for data about chlorides and made the forecast for the sought period of time y_t using the following formula:

$$\bar{y}_t = \frac{1}{k}\sum_{t=n-k+1}^{n} y_t$$

k – smoothing constant, t – period of time, n – the number of tests of the parameter yt.

The forecast is equal to the arithmetic average of the last three terms in the series.

RESULTS

Trend changes in groundwater quality in the time system have been set for groundwater of Quaternary and Triassic aquifer intaken in the foreland of the landfill by piezometers Q1 and T1. The paper shows using 3-regular moving averages for the determination of chloride ions in 1991–2012. Results of calculation of 44 periods in both piezometers are shown in table 1.

It was made a forecast for both piezometers in the case of missing data. On this basis, we calcula-

Table 1. Summary statistics for chlorides in piezometers T1 and Q1
Tabela 1. Zbiorcze dane statystyczne dotyczące chlorków w piezometrach T1 i Q1

Period t	Date	Value (mg/dm^3) for T1	Moving average For T1	Value (mg/dm^3) for Q1	Moving average for Q1
1	I/1991	10,2	-	6,8	-
2	II/1991	11,4	11,5	5,7	6,3
3	I/1992	12,9	15,07	6,4	10,13
4	II/1992	20,9	21,93	18,3	15,57
5	I/1993	32	25,3	22,0	27,4
6	II/1993	23	22,97	14,5	16,17
7	I/1994	13,9	19,63	12,0	11,25
8	II/1994	22	15,93	7,25	9,15
9	I/1995	11,9	14,3	8,20	10,15
10	II/1995	9	10,73	15,0	10,53
11	I/1996	11,3	10,77	8,4	12,8
12	II/1996	12	15,1	15,0	11,13
13	I/1997	22	18,67	10,0	14,67
14	II/1997	22	22,83	19,0	18,0
15	I/1998	24,5	16,32	25,0	28,0
16	II/1998	24,5	25,3	40,0	48,67
17	I/1999	27	26,17	81,0	47,0
18	II/1999	27	26	20,0	77,0
19	I/2000	24	25	130,0	59,3
20	II/2000	24	24,3*	28,0	108,3
21	I/2001	-	24,43*	167,0	118,3
22	II/2001	-	30,99*	160,0	149
23	I/2002	43,66	37,21*	120,0	143*

24	II/2002	43,66	44,1	-	102,67*
25	I/2003	45	44,55	39,0	77*
26	II/2003	45	46,3	43,0	38,3
27	I/2004	49	46,67	33,0	42
28	II/2004	46	51,83	50,0	38,67
29	I/2005	60,5	54,5	33,0	38
30	II/2005	57	57,5	31,0	36,17
31	I/2006	55	54,5	44,5	31,83
32	II/2006	51,5	59	20,0	29,83
33	I/2007	70,5	61,3	25,0	23,3
34	II/2007	62,0	62,5	25,0	21,17
35	I/2008	55,0	57,67	13,5	19,89*
36	II/2008	56,0	58,3	-	17,06*
37	I/2009	64,0	61,5	16,5	16,22*
38	II/2009	64,5	64,83	11,0	13,83
39	I/2010	66	67,5	14,0	87,33
40	II/2010	72	73,3	237,0	96
41	I/2011	82	79	37,0	101
42	II/2011	83	84,3	29,0	49,33
43	I/2012	88	90	82,0	75,67
44	II/2012	99	-	116,0	-

* The results of monitoring studies for piezometer Q1 does not contain data from 2002 and 2008, and for T1 data from 2001. This results was omitted because their bad representativeness.

ted moving averages for this periods. These results have only theoretical importance, which do not take into account the environmental aspects. The results of calculation of moving averages in these two boreholes is presented in fig. 2.

The collected data indicate that the chloride content in groundwater piezometers Q1 and T1 at the relevant time was variable. The data from the beginning of the 90s of the twentieth century indicate that the initial concentrations of Cl- were about 10 mg/dm^3 for water taken from the Triassic aquifer and about 5–7 for water intaken from Quaternary aquifer.

In the years 1992 to 2001 upward trend (with some fluctuation) of chlorides concentration was observed in groundwater of the Quaternary aquifer. The maximum concentration amounted 237 mg/dm^3. Currently we observe downward trend. The data obtained in the transition front contaminants were varied and ranged from 10–237 mg/dm3. Using of the moving averages method to determinate trends is very helpful with reducing the large variation in concentrations and clearly outline the transition curve. We have to remember that low concentrations of Cl- (20, 28 mg/dm^3) may be due to incorrect sampling of the piezometer Q1. But this statistical method can`t solve this kind of problem.

In the case of piezometer T1 in 1992–1994 observed a temporary increase in the concentration of chlorides then in 1995–1996 there was a decrease to the level of the early 90's. It has been an evident upward trend since 2001. Upward trend in 2001 coincides with the concentration of chlorides in groundwater in piezometer Q1.

Because the chlorides are very good indicator of contamination, variability Cl- concentrations should be associated with the activities of the landfill. New waste and new leachates generates higher concentration of chlorides in groundwater. For example higher concentration of chlorides in 1998 in Quaternary aquifer may be associated with the start of new exploitation metallurgical waste. Triassic aquifer istn`t threatened so much as Quaternary because it is isolated from the surface by younger sediments (DĄBROWSKA, SOŁTYSIAK, in press).

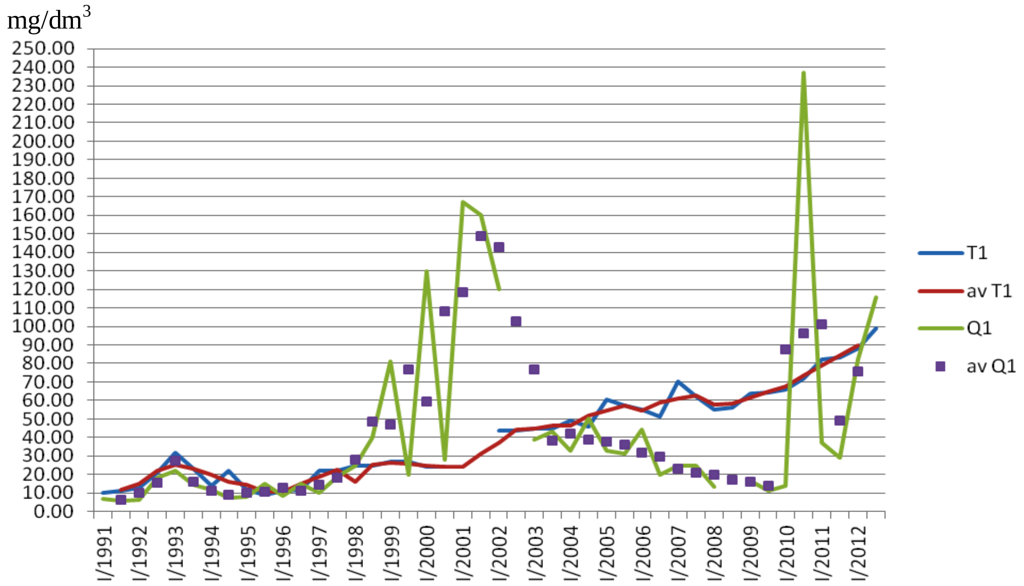

Fig. 2. Concentration of chlorides and moving averages (av) in groundwater in piezometers T1 and Q1
Rys. 2. Zawartość chlorków i wartości średnich ruchomych w wodach podziemnych piezometrów T1 i Q1

SUMMARY

The determination and estimation of trends in the assessment of groundwater quality is very useful for time course analysis with additional forecast. Using describing method is very simple to calculate.

However, it is worth noting that the assessment of the chemical status of groundwater with statistic should be supported by recognition of the geological structure and hydrogeological conditions a case study.

In the case of groundwater from piezometers Q1 and T1 the influence of metallurgical landfill Lipówka was highlighted – high concentrations of chlorides in both boreholes in the same time. Data from groundwater of these aquifers show that the transition of curve chlorides was clearly outlined in Q1 in relation to the piezometer T1. The main source of chlorides in groundwater in this anthropogenic environment is activity of landfill. The intensity of the leaching process is connected with the type of deposited waste and its hydrogeological parameters.

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