DE GRUYTER OPEN

Environmental & Socio-economic Studies

DOI: 10.1515/environ-2016-0025

Environ. Socio.-econ. Stud., **2016, 4, 4: 61-67**

Original article

The smoothing methods used in assessing the influence of pollution sources on groundwater quality – a case study of metallurgical landfill in Lipówka (southern Poland)

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ABSTRACT

Several methods have been used to determine trends in hydrogeochemical elements. This study is concerned with the ordinary 3-period moving averages, the 3-period moving median and the exponential smoothing method. It has taken into account the chloride concentration in groundwater from the region of the landfill of the Katowice Ironworks (southern Poland). The data from two piezometers were used: T1 screened in the Triassic and Q1 screened in the Quaternary aquifers. The main aim of this article was to compare statistical methods and to choose the most appropriate method for an assessment of the impact of pollution sources on groundwater quality and determining any trends. The choice of chlorides as the analyzed indicator is connected with their chemical conservative character. They are also indicators of negative impact on groundwater of e.g. municipal, metallurgical landfill sites on groundwater. Results showed that the moving median is less sensitive to outliers than the moving average. The running median preserves sharp discontinuities in the signal but the biggest smoothing was observed in the case of exponential smoothing. All of these methods filter out the noise and transform the data into a smooth curve, which is unbiased by outliers. Application of the smoothing method allowed the generalization of the monitoring data which clearly showed trends. In the absence of reliable data for short periods, these statistical methods made it possible to fill in missing values. These methods are easier to calculate than regression models even if they ignore complex relationships in the data. Moreover, they can also be used as a component in many other indicators such as the Moving Average Convergence Divergence.

KEY WORDS: moving average, moving median, exponential smoothing average, trends, hydrogeology

ARTICLE HISTORY: received 10 July 2016; received in revised form 3 September 2016; accepted 20 October 2016

1. Introduction

Landfill sites are potential groundwater pollution sources. In the region of sources of contamination, it is necessary to conduct reliable monitoring of groundwater quality, which will allow a proper assessment of the influence of the landfill activity on the groundwater and facilitate planning measures for counteracting the negative effects of contamination (NIELSEN ed., 2006; JOUSMA & ROELOFSEN, 2004; MCGRATH ET AL., 2001; QUEVAUVILLER ET AL., 2009). Those landfill sites which fulfill modern environmental standards are carefully isolated from the soil and water environments (SOBIK, 2007). In this case, the substances leached by precipitation infiltrating the landfill are captured by the drainage system, and then discharged into sealed containers. Some landfill sites, especially the older ones, do not have any ground security like polyethylene geomembranes (BOJAKOWSKA, 1994). In this case, precipitation with leached substances from the landfill, after infiltration through the zone of aeration, can enter the aquifer and be a threat to groundwater.

The main goal of groundwater network design is to observe the landfill impact assessment.

The regulations are included in the Regulations of the Minister for the Environment of 30 April 2013 on the landfill of waste (OJ dated 2 May 2013 Pos. 523 (ROZPORZĄDZENIE..., 2013). In the case of sealed landfill sites, the emergence of contaminants indicates a lack of isolation. In the case of non-insulated ground landfill sites the monitoring networks allow us to determine the real impact of landfill sites on groundwater. In accordance with the Regulation of waste land in the case of exploited landfill sites sampling is made every quarter and the samples are subjected to physical and chemical analyses. Analysis of the collected data leads to conclusions about the impact of landfill sites on groundwater. Inferences are made by reference to the actual concentration levels of the individual components to the concentrations present before the start of the landfill operation. Further analysis allows the determination of physico-chemical processes in the water and allows forecasts to be constructed based on them. This article presents the use of three statistical methods: the moving average, the moving median and exponential smoothing. A sample analysis was performed for one of the chemical elements (chloride) indicated in groundwater in the region of the metallurgical landfill site of Lipówka in Dąbrowa Górnicza (Fig. 1).

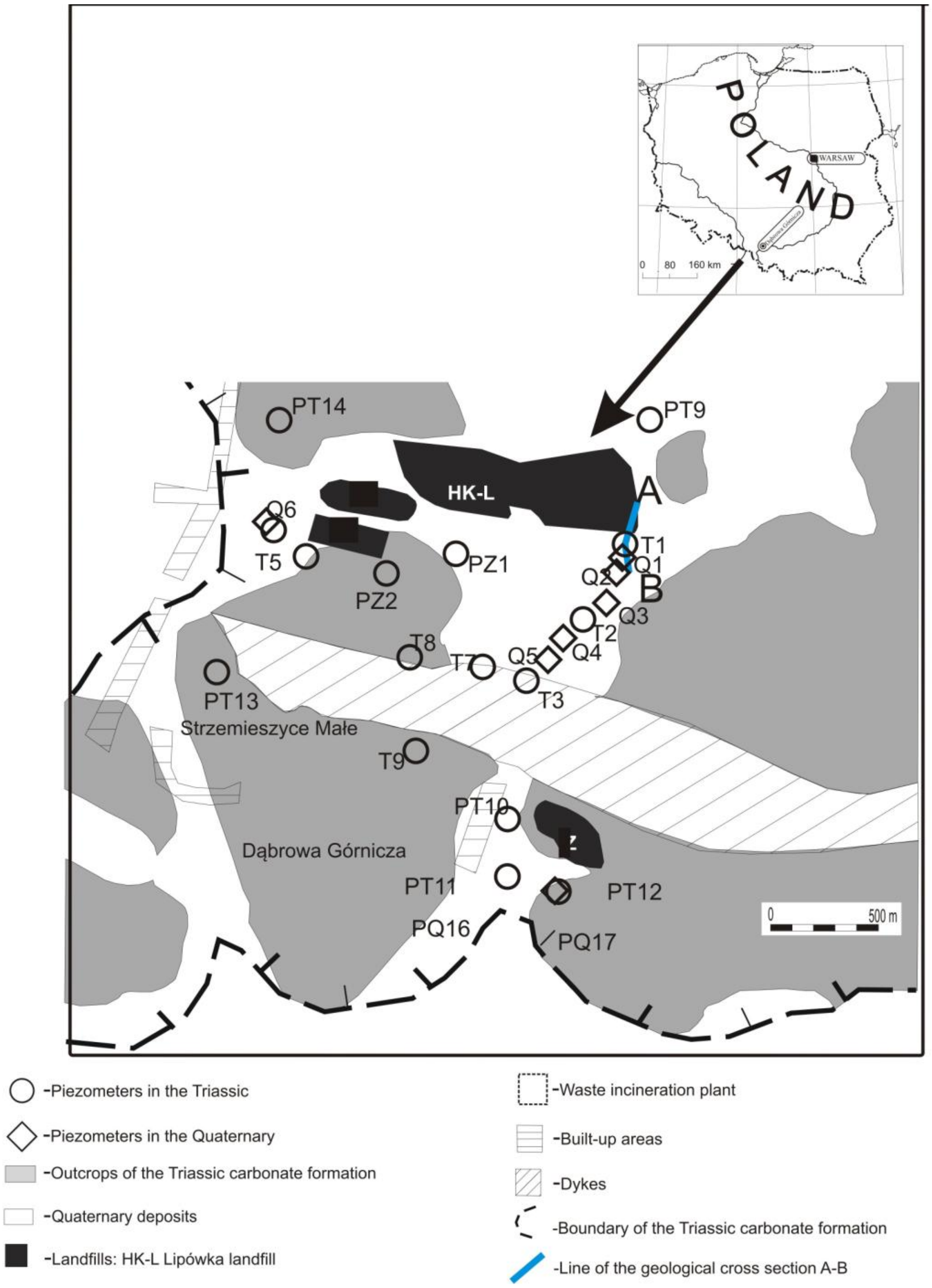

Fig. 1. The location of Lipówka landfill site

2. Lipówka landfill site – location and hydrogeological conditions

The Lipówka landfill site, which is landfilled waste from the steel industry, is located in the district of Dąbrowa Górnicza – Strzemieszyce and covers an area of over 45 hectares (Fig. 1). Iron waste has been deposited there since 1985. The landfill isn't sealed below the ground. In 2004, the total amount of waste deposited was 7.9 million tons. The maximum thickness of waste is more than 30 m. The composition of waste constitutes: metallurgical slag 68.04%, dust from the Thermal - electric power station 14.01%, rubble 12.02%, sludge from an industrial sewage treatment plant 4.65%, less also silt (from gas treatment furnaces), hearth slag and mill scale in small amounts. Until the early 1990s about 700 to 1500 thousand tons of waste per year was deposited. Then, the storage of waste showed a downward trend. New exploitation metallurgical waste was deposited in the landfill in 1998.

The Lipówka metallurgical landfill site was run without being isolated, and positioned in the zone of Triassic tracks outcrops, shaped as marls and dolomites. These deposits form the recharge zone of the Main Groundwater Reservoir 454 Olkusz-Zawiercie, and the groundwater surface in the area of the landfill is located at a depth of 8-10 m below the ground. There are Quaternary deposits over the Triassic formations in the eastern part of the landfill site. The eastern part of the landfill was located in the Quaternary filling of the Zakawie Valley and here the surface of the groundwater in the aquiferis located at a depth of about 5-6.5 m below the ground (Fig. 2).

There are piezometers Q1 and T1 next to the landfill site within the Zakawie valley, respectively in the Quaternary and Triassic aquifers. They form part of the Lipówka landfill monitoring network. Piezometers Q1 and T1 are located closest to the landfill intercepting water coming from the direction of the metallurgical landfill. It is worth mentioning that in the region of Strzemieszyce, near the metallurgical waste landfill, there are also other landfill sites, which have their own monitoring networks.

This research focuses on the chlorides, as a conservative non-sorption indicator, migrating with the same speed as the flow (Baran & Turski, 1995; Macioszczyk, 2002). 50 chemical analyses have been performed for the Q1 piezometer since 1989, and 48 analyses for piezometer T1. In the first stage the analyses were verified by checking the compatibility with the ionic balance sheets. It was necessary to work only with reliable data. In this way the number of analyses was reduced to 27 and 26 for Q1 and T1 respectively.

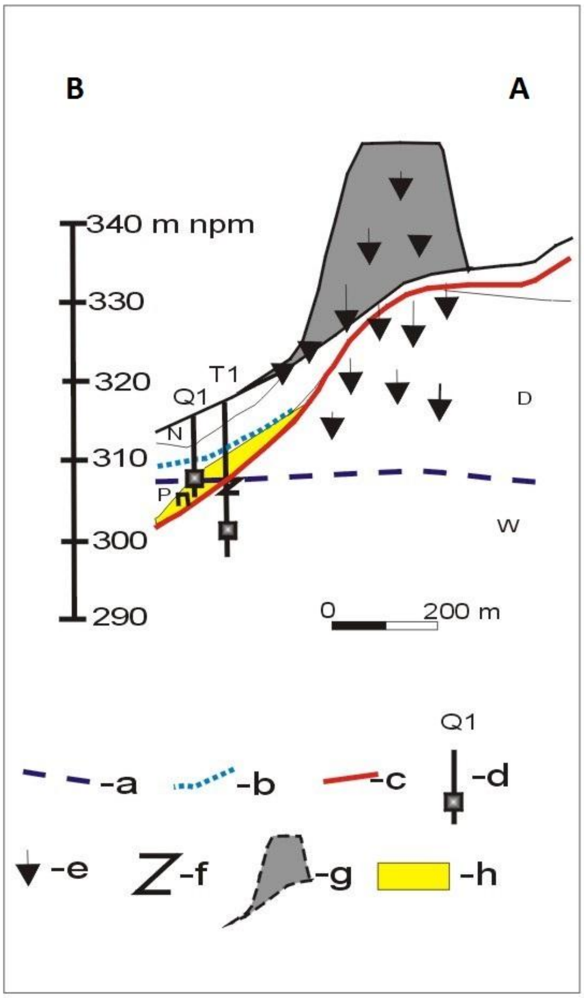

Fig. 2. Hydrogeological cross section N-S through the area of the metallurgical Lipówka landfill site
(a) groundwater table in the Triassic sediments; (b) groundwater table in the Quaternary sediments; (c) stratigraphic boundary; (d) piezometer; (e) direction of seepage from the landfill; (f) confined table; (g) the Lipówka landfill; (h) poorly permeable Quaternary sediments; (w) limestone; (D) dolomites; (P) sands, (Π) dust; (N) embankment

3. Methodology

Determination of trends in water quality requires the identification of the initial chemical composition of the groundwater. When we test water under the influence of anthropogenic impacts, it is also necessary to determine the degree of risk to the quality of groundwater (Gogu & Dassargues, 2000; Dowgiałło et al., 2002; Krogulec, 2011).

For an assessment of the degree of transformation of the chemical composition of the groundwater it is helpful to determine the hydrochemical background. Hydrochemical background 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). Hydrochemical background can be set for layers, or levels, of aquifers and it is also diverse in terms of the complexity of the defined parameters - we distinguish partial background (e.g.; background of chloride) or general background, consisting of several specific ranges of parameters (KMIECIK, 2005).

There are several methods for determining the hydrochemical background. Most accurate are graphical or statistical methods. For one vertex distribution statistical methods are used in which the range of the background of the individual water components may be defined as the mean (x) ± 2 standard deviations (s), medium (x) ± 3 standard deviations (s), the median (m) ± 3 standard deviations (s) or 1.96 standard deviation (s) (MACIOSZCZYK, 2002). The representative and reliable hydrogeological results of groundwater monitoring allow us to determine more accurately the hydrogeochemical background through determination and analysis of the trend in changes of the water quality.

An assessment of the trends requires the use of average values of chemical components for each of the studied piezometers. According to the Regulation of the Minister for the Environment of 30 April 2013 /OJ No. 523, item. 21/ (ROZPORZĄDZENIE..., 2013) concerning the landfill of waste, groundwater in the region of inactive landfill sites should be monitored twice a year and once a quarter in the area of active landfill sites. Trend assessments of change in quality must be based on a long sequence of measurements.

Determining the trend is also called smoothing the time series, and is made by analytical and mechanical methods. Analytical methods rely on the modelling of contents in groundwater using regression analysis, while the mechanical method is based on the elimination of random variation by converting linear time series.

The elimination of accidental factors during the investigation time period is feasible using a simple moving smoother method (average or median). Moving average is called the arithmetic mean of the number of consecutive elements (HYNDMAN, 2014). The length of the moving smoother can be chosen so that seasonal changes in the concentration of the chlorides will be completely suppressed (KOT ET AL., 2007).

It is assumed that the length of the moving smoother should be equal to the period of fluctuations, e.g., different concentrations of a given component in groundwater caused by seasonal changes in the hydrodynamic system.

The method for determining trends using the moving smoother is quite simple, which is a great advantage. Random factors aren't required for short-term forecasting. The disadvantage of the simplified calculation is shortening of the time series. The estimate of the local mean will tend to lag behind the true value of the local mean by 2 periods in the case of a 3 period moving average. The lag indicator is reduced for the short periods method.

To show the method of moving averages for short-term forecasting results, the chloride content for the missing years was estimated. The forecast for the missing period of time y_t can be done using the formula:

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

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

The moving median method (SMM) is similar but the average is replaced here by the median.

Another method is that of exponential smoothing (ES). In this method older data is given progressively-less relative weight (importance), whereas, newer data is given progressively-greater weight (ASTERIOU & HALL, 2011). The difference between a SMA and exponential moving average is that the EMA is consistently closer to the actual concentration of chlorides. The general formula for calculating ES is the following:

$$L_t = \alpha Y_t + (1-\alpha)L_{t-1} \quad (2)$$

L – current level (local mean value) of the series as estimated from data up to the present
t – period of time
α – smoothing constant
Y – value of measurement

4. Results and discussion

Trend changes in the content of chlorides in the time system have been set for the groundwater of the Quaternary and Triassic aquifers taken within the landfill by piezometers Q1 and T1. This article shows the effect of smoothing the time series with the methods of ordinary moving averages and moving median (3-periods based on the whole past year and one extra result), and exponential smoothing with an automatic value α=0.2 for the determination of chloride ions during 1991-2004. The unknown parameters and the initial values for these methods were estimated by minimizing the Error Sum of Squares (SSE). The data set is shown in Table 1.

Table 1. Chloride concentration in piezometers T1 and Q1 in years 1991-2004

Period t	Date	Value (mg/dm³) for T1	Value (mg/dm³) for Q1
1	I/1991	10.2	6.8
2	II/1991	11.4	5.7
3	I/1992	12.9	6.4
4	II/1992	20.9	18.3
5	I/1993	32.0	22.0
6	II/1993	23.0	14.5
7	I/1994	13.9	12.0
8	II/1994	22.0	7.25
9	I/1995	11.9	8.20
10	II/1995	9.0	15.0
11	I/1996	11.3	8.4
12	II/1996	12.0	15.0
13	I/1997	22.0	10.0
14	II/1997	22.0	19.0
15	I/1998	24.5	25.0
16	II/1998	24.5	40.0
17	I/1999	27.0	81.0
18	II/1999	27.0	20.0
19	I/2000	24.0	130.0
20	II/2000	24.0	28.0
21	I/2001	-	167.0
22	II/2001	-	160.0
23	I/2002	43.66	120.0
24	II/2002	43.66	-
25	I/2003	45.0	39.0
26	II/2003	45.0	43.0
27	I/2004	49.0	33.0
28	II/2004	46.0	50.0

The results of monitoring studies for piezometer Q1 do not contain data from 2002, nor from 2001for T1 data. The ionic balance of these chemical analyses contained a big error, therefore, the analytical results were considered unreliable and ultimately omitted. Missing values were replaced by values obtained from the three tested methods.

The replaced results are only theoretical values, which do not take into account the chemical processes and the impact of external factors on the concentration of chlorides in the groundwater analysed. The obtained values and the results of the moving average, the moving median and the exponential smoothing method have been shown by graphs imaging the trend changes in the concentration of chloride in two piezometers (Figs. 3-5).

The data collected indicate that the chloride content in the groundwater piezometers Q1 and T1 during the stated time was variable. The data from the beginning of the 1990s indicate that the initial concentrations of Cl^- were about 10 mg/dm³ for water taken from the Triassic aquifer and about 5-7 mg/dm³ for water taken from the Quaternary aquifer.

In the years 1992 to 1998 upward trends of chloride concentrations were observed in groundwater in the Quaternary aquifer to the level of 10-25 mg/dm³ (culminating in 1993), the upward trend in the concentration of this ion had been observed up until 2001. The maximum concentration amounted 167 mg/dm³. By 2004, the Cl^- concentration dropped to 30-50 mg/dm³. The concentration distributions clearly show a transition in the accumulation of pollutants in which one of the ingredients has been chloride - one of the characteristic pollutants of steel industry waste (MACIOSZCZYK, 2002). The data observed during the transition contaminant front were varied and ranged from 20-167 mg/dm³. The application of the moving averages method helped reduce the large variation in concentrations and clearly outlined the transition curve. The median, however, is a robust measure of central tendency and highlights the outliers. The most advanced smoothing has been observed in the case of the exponential smoothing method. This method shows an almost steady increase in the chloride content.

In the case of the T1 piezometer a temporary increase in the concentration of chlorides was observed in groundwater of this aquifer in 1992-1994 (as in the case of water from the Q1 piezometer), then in 1995-1996 there was a decrease to the level of the early 1990's. Then the trend is upward to about 25 mg Cl/dm³ (culminating in 1998). The years 2001/2002 highlight a clear upward trend of about 45 mg/dm³, which correlates with the abrupt increase in the concentration of chlorides in groundwater taken in the Q1 piezometer.

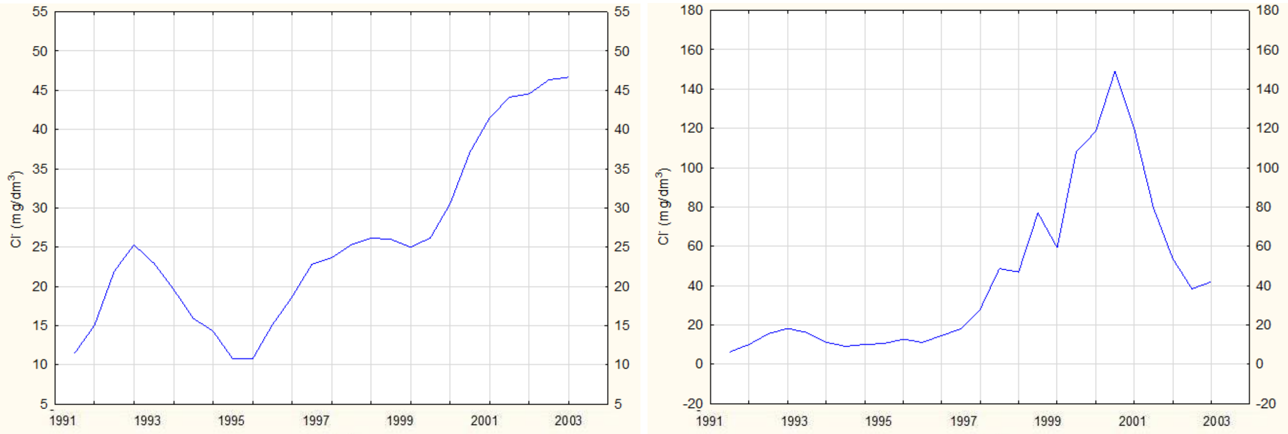

Fig. 3. Changes in chloride content in piezometers T1 and Q1 obtained with the moving average method

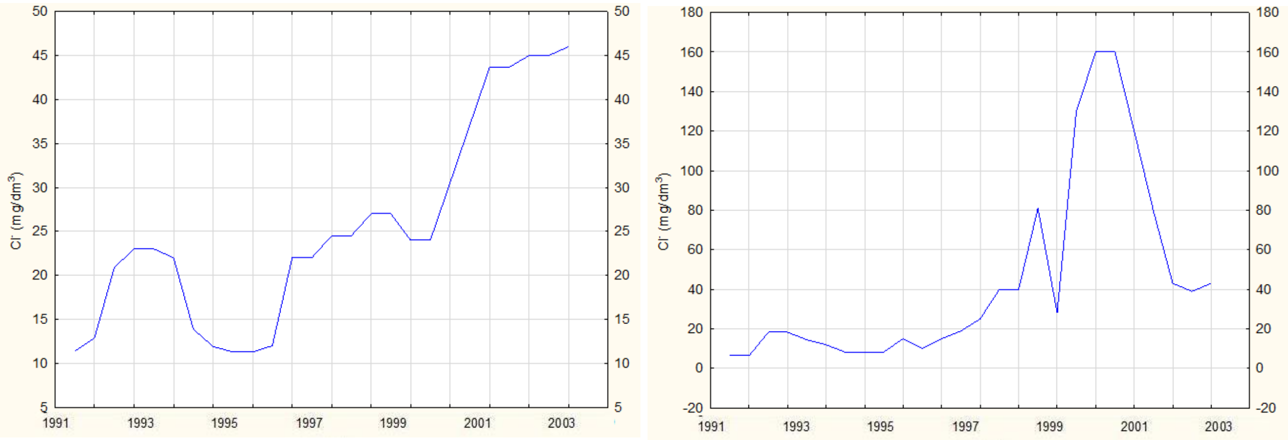

Fig. 4. Changes in chloride content in piezometers T1 and Q1 obtained with the moving median method

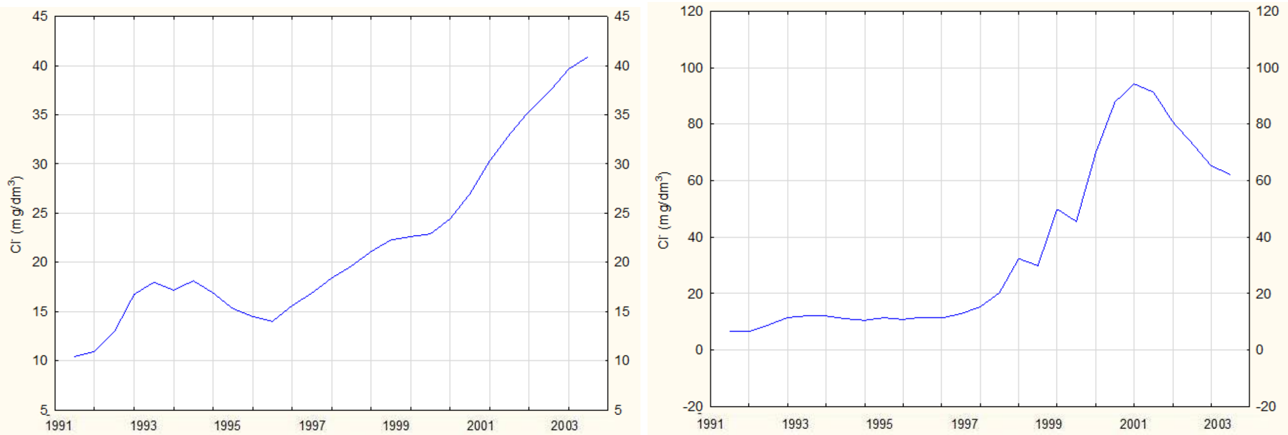

Fig. 5. Changes in chloride content in piezometers T1 and Q1 obtained with the exponential smoothing method

A wide range of Cl^- concentrations could be associated with the activities of the landfill - depositing new waste and leaching substances including chlorides. For example, in lysimeter studies a concentration of 2.2 g Cl /dm^3 was obtained from 1.2 m^3 of waste leachates, (SOŁTYSIAK, 2007). Wastes are subject to rapid leaching, the intensity of the leaching process is related to the amount of rainfall as well as the nature of the deposited material. The transition of the chlorides in the years 1998 - 2004 in the Quaternary aquifer may be associated with the start of new exploitations of metallurgical waste deposited in the landfill in 1998. The highest concentration of chlorides was found in the first aquifer nearest the surface. This concentration is also highlighted in the groundwater of the Triassic aquifer, but in lower concentrations and also with a delay resulting from the longer seepage duration into the aquifer in Triassic formations within the Zakawie valley which are isolated by Quaternary deposits.

5. Summary

Analysis of the trends in the assessment of groundwater quality is very useful in order to determine the changes in physico-chemical parameters over time. It also allows short-term forecasting of changes in these physico-chemical parameters. Determination of trends using moving averages or median and exponential smoothing is straightforward to calculate and to use. These algorithms have motivated some of the most successful forecasting methods. Forecasts produced using exponential smoothing or moving averages require a thorough analysis of the geological structure and hydrogeological conditions of the audited entity. Statistical methods for the assessment of groundwater quality changes are a valuable tool as long as the inference is accompanied by analyses of the impact of the factors that may cause changes in the chemical composition of water, such as the creation of new pollution sources, fluctuations in the level of infiltration, changes in water relations, earthworks, and formation of new objects, etc.

In the case of groundwater from the piezometers analyzed the influence of the metallurgical landfill at Lipówka was observed – shown by an increased trend in relation to the background concentrations of chlorides. Between the years 1992-2004 an increasing concentration of chlorides was observed in groundwater taken by the T1 piezometer. A similar phenomenon was found in groundwater from the Q1 piezometer, but in this case the transition in the chlorides curve was clearly outlined. Changes in chemical composition of groundwater could be associated with the activities at the landfill site such as depositing new waste and the leaching of contaminants.

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