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Author: Mateusz Mycka, Maciej Jan Mendecki

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Mateusz Mycka[1], **Maciej Jan Mendecki**[1]

[1]*Department of Applied Geology, Faculty of Earth Science, University of Silesia, Bedzinska Str. 60, 41-200 Sosnowiec.*
E-mail: mateuszmycka@gmail.com

An application of geoelectrical methods for contamination plume recognition in Urbanowice waste disposal

Key words:
electrical resistivity, chargeability, contamination plume, landfill site, Urbanowice

Abstract

The purpose of this work was to detect groundwater pollution and to identify the conditions of soil and groundwater near the Urbanowice landfill site using geoelectrical measurements. Presented measurements are preliminary results from tested site and are beginning of continuous monitoring. Contamination outflows detected by resistivity and IP technique show a good correlation with available hydrological data. Contamination plume were found in Eastern part of survey profil.

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Introduction

Electrical resistivity surveys have been used for many decades in hydrogeological, mining and geotechnical investigations. More recently, it has been used for environmental surveys. The goal of electrical measurements is to determine the subsurface resistivity distribution of landfill contamination plume and surrounding soils. From surface surveys the apparent resistivity is obtained and the real resistivity of the subsurface can be estimated by application of inversion techniques.

Contamination outflow monitoring is important in environmental protection issues. The outflow can appear from coal waste disposal (Kowalska & Mendecki 2010, Kowalska et al. 2012), settling reservoir (Antoniuk & Mościcki 1996) and urban landfills. In Urbanowice landfills area geoelectrical monitoring did not occur, only spot water probe from piezometers were carried out. Result of this paper are beginig of geophysical monitoring in Urbanowice landfill.

Study area

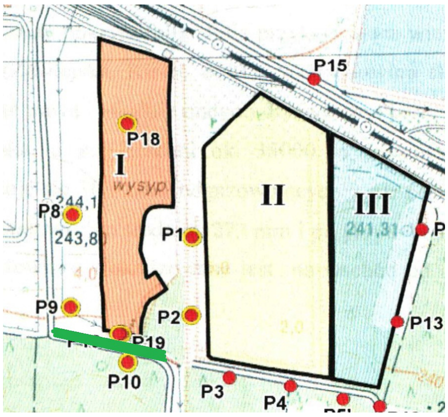

Fig.1. Location of measurement points and the spatial distribution of landfills in Tychy – Urbanowice. Green line is the survey profile (Intergeo 2006).

Old landfill

Old closed landfill is located in the eastern part of Tychy, in the district Urbanowice. In the immediate vicinity a new municipal landfill is located and it consists of two units: I on West and II-III on East (Fig. 1) and access roads situated on the west and south. At a distance of over 200 m in south direction the sewage treatment plant were built. Old Landfill with an area of approximately 3.5 hectares, functioned originally (before 1988) as landfill construction. Since 1988 it has served as a municipal landfill of Tychy. The landfill was not in any way protected from the possibility of penetration of pollutants into groundwater because in landfill bottom sealing did not exist. It also did not have a leachate drainage system. Since 1994, the landfill was closed. In autumn 1996 the surface recultivation of inactive landfill was started. Lined sand layer covered the landfill surface was covered once again by HDPE foil with a thickness of 1.5 mm. Next the HDPE cover was obscured with a layer of ground with a thickness of 30-70 cm. Slopes of the site have not been covered with the foil (foil covered only the plateau and exceed beyond plateau just 1 m). Re-cultivation works on the crown of the site, on the area of about 35000 m, was completed in March 1997. (Intergeo 2009)

The new landfill is located on the Easter side of the old, at the distance approximately 15-25 meters.

Geology

The identified geological profile (Intergeo 2007) in the area of old landfills consists of Quaternary, Miocene, Triassic (locally) and Carbon strata. The analyzed area is located within the Upper Silesian Coal Basin. In Urbanowice area, eroded sheets of Triassic platform occur on the upper Carboniferous strata. These sheets were found in the vicinity of the borehole Urbanowice (IG-23). The thickness of the Triassic reached 34 m, above Triassic layer the Miocene clayey deposits with a thickness of approximately 80 m is present (Intergeo 2007). The Miocene clays are covered by accumulation Quaternary deposits: mainly river sands of different grain size, locally there are layers of clay, silt and dust. The thickness of the Quaternary in this region is variable in the range of 12.5 - 17 m.

Hydrogeology

On the hydrogeological profile aquifers in the Quaternary, Triassic and Carboniferous rocks have been distinguished. Local groundwater aquifers were also found in sands or sandstone of Miocene. However, only Quaternary aquifer occurred directly under the old landfill are important in this work. Very poorly drained gray Miocene clays occur in the basement of Quaternary aquifers layers which are insulation for low-lying Triassic and Carboniferous aquifers. For this reason, the lower water aquifers are not affected by anthropogenic pollution generated on the surface (Intergeo 2009).

In the study area Quaternary aquifers are associated with sandy-gravel layers. They are treated as one aquifer locally distributed by poorly-drained two loamy-silt layers remaining in hydraulic communication. This aquifer layer system is very important from the point of view of spatial migration of contaminants in groundwater. The water table is located at a depth from 1.95 m below the ground (at the piezometer P15, see Fig.1) up to about 8 m below ground level (at the piezometer P8, see Fig.1). Groundwater flow occurs from North to South direction (Fig. 2) (Intergeo 2009).

Methods

Resistivity

The fundamental physical law used in resistivity surveys is Ohm's Law that governs the flow of current in the ground. The equation for Ohm's Law in vector form for current flow in a continuous medium is given by (Telford et al 1990; Schön 1996, Loke 2004):

$$I = \sigma \ E$$

where σ – the conductivity of the medium, I – the current density and E – the electric field intensity.

In practice, what is measured is the electric field potential. It should be noted that in geophysical surveys the medium resistivity ρ, which equals to the reciprocal of the conductivity, is more commonly used (Schön 1996). Resistivity Imaging Method connects features of resistivity lateral profiling and resistivity sounding (Rudzki, 2002; Loke, 2004). Process of inversion is essential for this method. Determined apparent resistivity values are used during this process to determine resistivity distribution of the rock mass based on theoretical model of the medium.

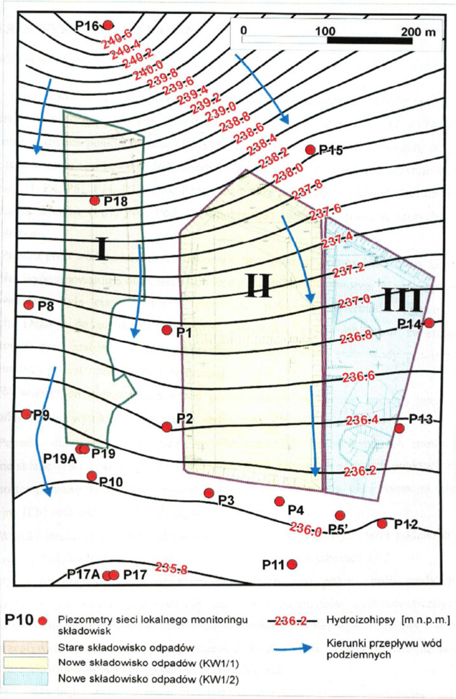

Fig.2. The map of hydroizohips of Quaternary aquifer in the area of waste disposal sites in Tychy-Urbanowice (Intergeo2009).

Chargeability

The occurrence of induced polarization (IP) is observed as the decay of response potential in geological environment which is induced by external electric field. Relaxation of this effect may be described and measured in the time domain and the frequency domain, and the relations between domains describe the Fourier Transform (Schön, 1996). In a first approximation, the phenomenon of induced polarization with the rising and fading of electrical potential over the time is analogous to the charging and discharging of the capacitor in RC circut. However, the decay curves represent different forms of relaxation to equilibrium state of electricity. For rocks, this is a logarithmic-like function, and decreases more gently than the exponential curve of the voltage drop in the system RC (Telford et al. 1990).

The IP phenomenon is caused by electrochemical mechanisms such as current forced ion diffusion near metallic-luster and non-metallic minerals and redox reactions between electrolytes and minerals (Sumner 1976). These processes are related to the ion mobility, the surface area of materials and the surface charge density or cation exchange capacity (Sumner 1976, Milsom 2003). The kind of IP effect depends on the type of the current minerals occurring in the rock skeleton and in the pore space. There are two general model types: the electrode polarization associated with ore-minerals and the membrane polarization related with the presence of clay minerals(Sumner, 1976).

When a DC current flowing in the ground is suddenly terminated, the voltage Vo drops abruptly to a small polarization voltage Vs and then starts to decline gradually over time V(t) asymptotically to zero (Milsom 2003). As mentioned above, the induced polarization voltage decay is the process of discharging geological environment. Measurable parameter of the discharging process in the time domain is called chargeability M and it can be expressed as:

$$M=\frac{1}{V_0}\int_{t_i}^{t_{i+1}} V\left(t\right)dt$$

(2) where ti and ti+1 denote the start and end of the measuring time window, Vo is the voltage measured at the time of current flow, V(t) is the induced potential disappearing after cutoff current (Sumner, 1976; Telford et al., 1990; Schön, 1996).

Data inversion

The goal of inversion is to find such set of model parameters, which minimizes the squared differences e between the observed d and computed data f (forward modeling) for all data points (Loke et al. 2003; Loke 2004):

$$\min\left\{e^T e\right\}=\min\left\{\left(d-f\right)^T\left(d-f\right)\right\}$$

(3)The inversion routine used by Res2Dinv software is based on the smoothness-constrained least-squares method as follows:

$$\Delta m=\left(J^T J+\lambda F\right)^{-1} J^T e$$

(4) where F – matrix of flatness filters,
J – matrix of partial derivatives (Jacobian),
λ – damping factor, Δm – model perturbation vector, e – discrepancy vector

The process started with initial model parameters mo for both data set (resistivity and IP) which are modified by Δm vector in following iterations to fit the theoretical data to the empirical one. Always a new IP model is calculated after resistivity model evaluation. Iterative process is continued while the required convergence level is achieved (Loke et al. 2003; Loke 2004). Finally, resistivity and chargeability invers model are obtained.

Results and Discussion

Survey were carried out during the beginning of August 2013 and it has started contamination plume monitoring in study area. 100 m long survey line with minimum electrode spacing 2.5 m was chosen (Fig.1). Non-polarizable electrodes were applied. Measurement parameters were applied as follows: maximal current 100 mA, minimal current 10 mA, resistivity measurement time 0.5 s, number of chargeability windows: 5, window length 20 ms, initial delay 10 ms.

During the pre-processing procedure about 20 % of data points with high error were eliminated from data set. the inversion smooth-constrained least square algorithm was applied to estimate “real” resistivity and IP models. Final result after inversion are shown on Fig.3. Upper cross-section represents resistivity distribution in study area and lower cross-section shows chargeability changes in ground of study area. Inversion routine was stopped on 5th iteration. RMS error for resistivity distribution reached value 7.7 % and for chargeability distribution: 31.3. Both RMS error results are slightly large but still acceptable. Such values are effect of poor contact electrode-ground, because subsurface sediments were quite dry.

Three characteristic anomalies can be distinguished on resistivity plot. First with high resistivity value (>100 Ωm) situated near surface and two deeper structure with relative low value (<100 Ωm). Shallow structure is interpreted as vadose zone which consists of dry Quaternary sediments. Deeper structures are probably saturated sands.

IP cross-section presents two chargeability anomalies: left-side (East) and right-side (West). High IP response values are observed on the left side and this anomaly correlate with low-value resistivity zone. Considering both data, it can be noticed that Eastern part of cross-sections indicates the existence of pollution in water-ground system: low resistivity and high IP response. Western part is probably clear or less contaminated area. This interpretation was confirmed by hydrological data because main stream of groundwater underflow from landfill turns in left direction (Fig.2).

Presented results are the beginning of electrical properties monitoring of contamination plume. Satisfied models of resistivity and chargeability distribution allow to understand the nature of outflow from landfill in Urbanowice and to complement contamination knowledge. Next surveys are planning in the autumn season.

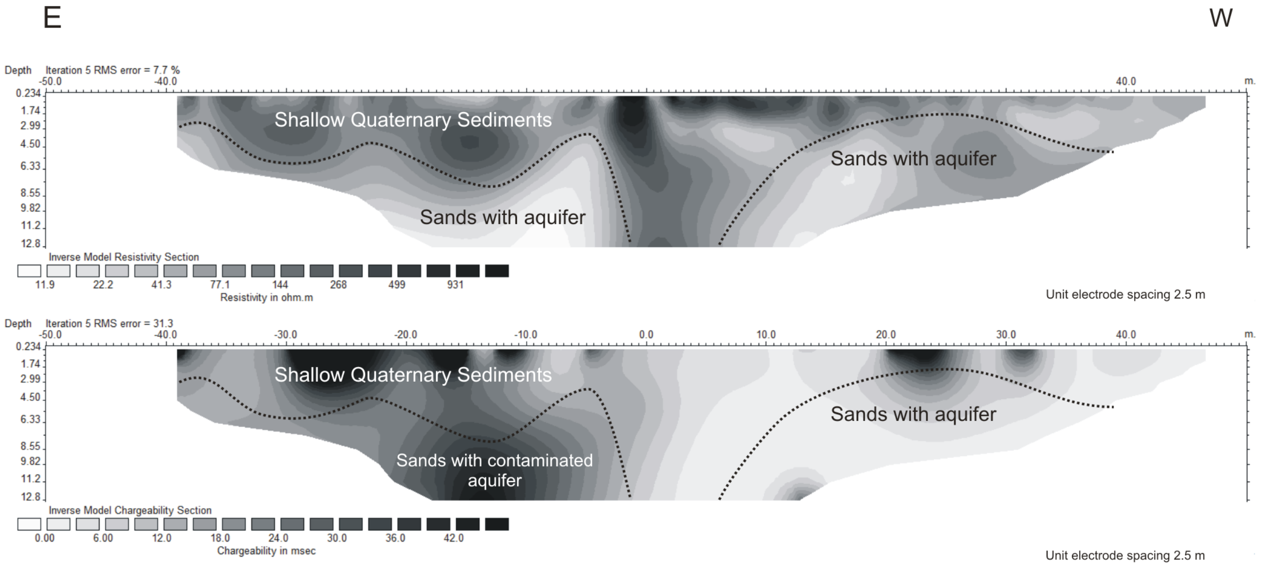

Fig.3. *Invers model of resistivity cross-sectrion (upper profile) and chargeability cross-section (lower profile) with marked boundary between vadose and saturated zone*

Acknowledges

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