APPLICATION OF RESISTIVITY-IP TO MAPPING OF GROUNDWATER CONTAMINATION AND BURIED WASTE

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Abstract

Combined resistivity and IP investigation is a powerful tool for mapping contaminant leakage as well as delineating the extent of contaminated ground and buried waste. Resistivity investigation is well established for detection and mapping of contaminated ground and groundwater. Low resistive zones around contaminated industrial sites and landfills correlate with high ion contents in groundwater due to leachate migration. A common problem is that the extent and composition of the buried waste is unknown due to poor or lacking documentation. Resistivity investigation alone can often not delineate the waste due to large variations in resistivity as a result of variation in water content. Time-domain induced polarisation (IP) can be used to measure the chargeability of the ground together with resistivity in a time and cost efficient way. Since buried waste commonly produces strong IP effects the chargeability can be used for delineating the waste. In this paper two field examples illustrate the use of this combined concept.

1. Introduction

Waste deposits and old industrial grounds constitute integral parts of the hydrological system and pose a serious threat of polluting both groundwater and downstream surface water. A number of problems frequently occur in connection with landfill surveys, and the problems tend to be interlinked and complex. There is generally a lack of documentation regarding both the extent and composition of deposited waste and chemicals, and the extension and status of soil covers at landfills are often uncertain. Geological formations, soil layers and bedrocks, underlying and surrounding landfills are often contaminated as a result of leakage of contaminants from the waste, and the landfill often poses a threat to groundwater resources around landfills. The same can apply to old industrial sites. The migration patterns of pollutants are often very complex due to variability of ground properties. Drilling and sampling can only be used to a limited extent due to high cost, difficulties in penetration and risk of creating contaminant leakage pathways by perforating barriers. Geophysical techniques, on the other hand, offer possibilities to map complex geology, and the extent of waste and pollutants in three dimensions (3D). Geoelectrical methods are suitable because electrical properties are strongly related to water content, salinity and porosity. Induced polarisation in particular has been used successfully for distinguishing buried waste from its surroundings. The combination of resistivity and time-domain induced polarisation (IP) has been shown to be a powerful tool to get an overview of landfills and pollution migration associated with them (Angoran et al. 1974; Iliceto and Morelli 1999; Carlson et al. 2001; Leroux et al. 2007; Dahlin et al. 2010). This paper describes and compares the results of resistivity and IP measurements at two sites in Sweden.

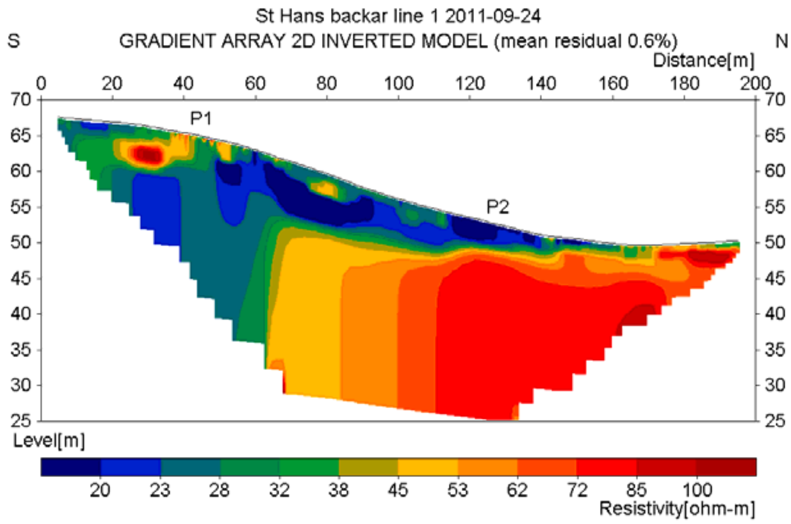
2. Method

Data acquisition was made with an ABEM Terrameter LS with 12 measuring channels. The IP data was recorded in time-domain by integrating 12 or 9 time-windows of around 4 or 1 s in total for the respective site, starting 10 ms after current turn-off. The inversion software used can, however, only handle one time-window so data was merged into one time window before inversion. At St Hans Backar 160 m long layouts with an electrode spacing of 2 m were used for measuring 3 lines with multiple gradient array, which were extended to a total length of 200 m each by roll-along. Each line took around half a day to complete for a group of un-experienced students. Data were inverted with Res2dinv using L1-norm (robust) inversion. One of the lines is presented here. At Filborna 300 m long layouts with 5 m electrode take-out spacing were used. A total of 11 lines 300 m long and spaced 10 m were measured in one field week, resulting in 17680 resistivity-IP data points on a total of 3300 m of profile. An expanded multiple gradient array, where potential measurements were taken outside the current electrodes in addition to between them, in order to improve resolution towards the end of the layouts. Data were inverted with Res3dinv using L1-norm (robust) inversion. The IP results are presented as normalised chargeability (Slater and Lesmes 2002).

3. Example: St Hans Backar

St Hans Backar in Lund is a former landfill that was converted to a park in the early 1970-ties. Landfilling was started in 1947 and lasted until 1967, and various types of household and industrial waste were deposited without documentation. After closure the landfill was covered by soil and the area was landscaped into a hilly park using additional soil masses. The dominating soil type in the cover is clayey till, which is also underlies the landfill to large depths, but other soils and building demolition material are also present. It was not properly documented exactly where there is waste and where there are soil masses. A problem today is that contaminant leakage seeps out from the landfill and contaminates a stream with malformation of fish as a result. In order to reduce the generation of contaminant leakage, the soil cover on top of the waste will be improved where needed to minimise infiltration of precipitation water into the waste. Therefore it is important to know where the waste is situated, and if there is adequate soil cover or not. Furthermore the drainage system will be redesigned which also requires knowledge about the subsurface distribution of materials.

a)



b)

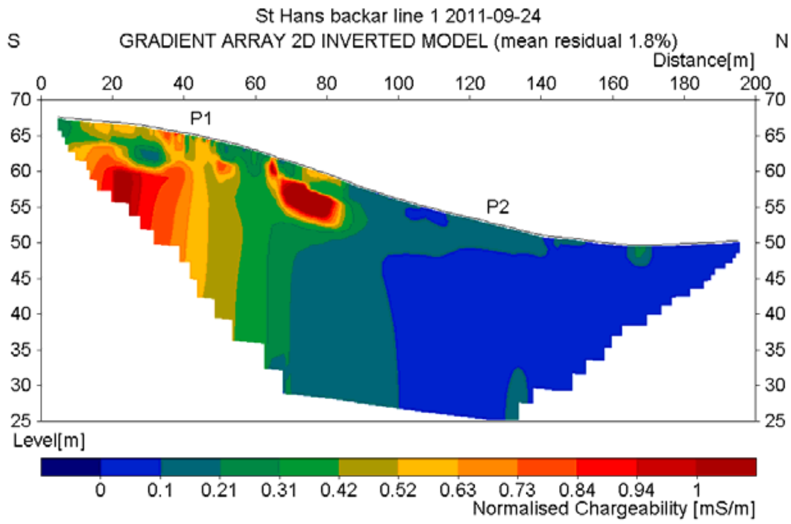


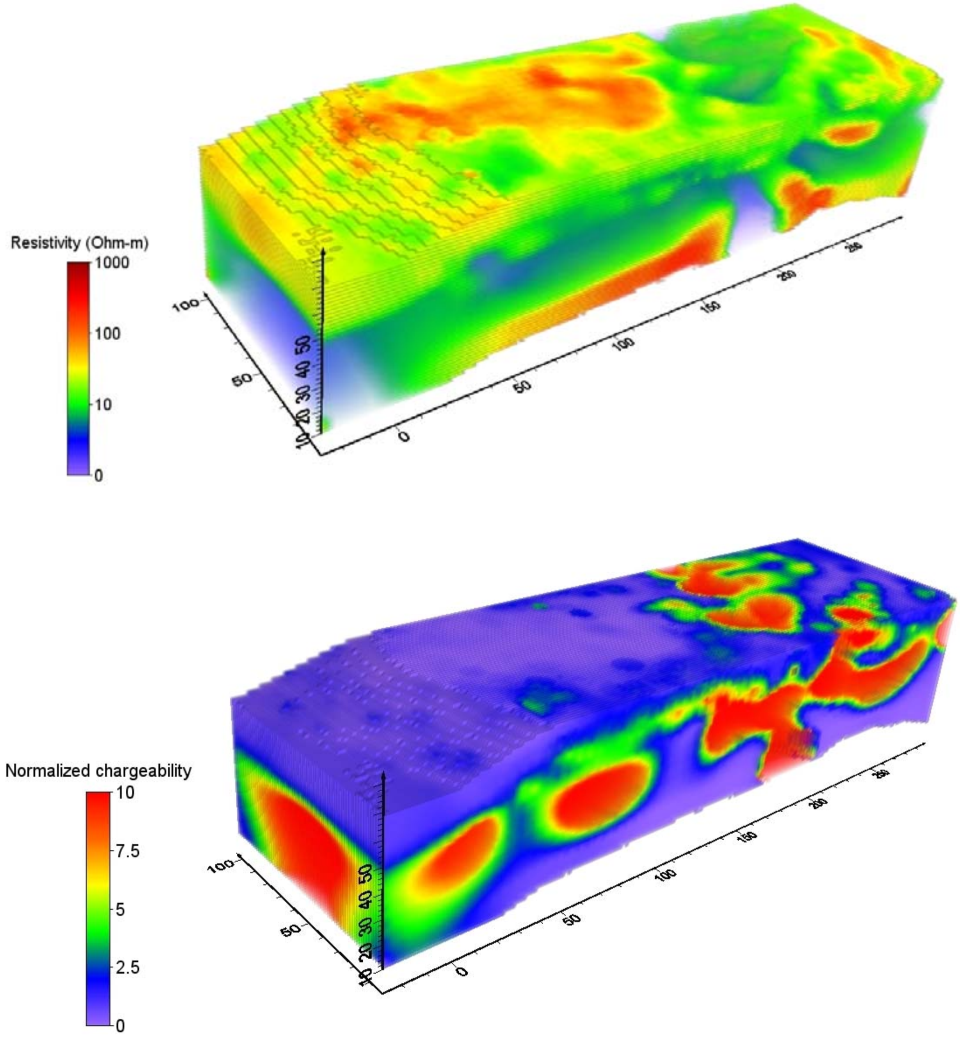
Figure 1. 2D inverted models from St Hans Backar; a) resistivity, b) normalised IP. P1 and P2 marks positions of test pits.

The line presented here was placed so that it was expected to start on the former landfill, extend across its border and end outside of it. The resistivity model (Figure 1a) shows a relatively complex structure, with a transition from low (<30 Ωm) to intermediate (>70 Ωm) resistivity going from left to right. A low resistivity (<23 Ωm) upper layer is distinct in the central part of the section, which coincides with seasonal outflow of contaminant leachate water around the area where test pit P2 is located. The left part of the section, where waste is expected to be present, exhibits strong variation in resistivity. The right half of the section, where natural soil is expected to be found, is characterised by resistivity in the range 60-80 Ωm which is typical of the till in the area around Lund (e.g. Dahlin 1996). The normalised IP section (Figure 1b) shows high chargeability in the left part of the section and little or no chargeability in the right part. This fits very well with the expected distribution of materials. The high chargeability material extends more or less to the ground surface in several places in the length interval 0-85 m, suggesting that there is hardly any cover on top of the waste. This was confirmed by test pit P1 where mixed waste was encountered at a depth of few dm. In test pit P2 clayey soil but no waste was found.

4. Example: Waste Characterisation at Filborna, Sweden

A 3D resistivity and time-domain induced polarisation (IP) survey was carried out over part of a Municipal Solid Waste (MSW) landfill, the Filborna landfill site, Helsingborg, Sweden. The objective was to assess the possibilities to map variations in material distribution in the landfill. Figure 2a shows the inverted resistivity model. At the bottom the model shows relatively high resistivity which corresponds to sedimentary rock, predominantly sandstone. At length coordinate 200 m a distinct low resistivity zone is visible, which corresponds to the position of a former stream below the landfill, indicating contaminant leachate migrating into the former stream. The lower part of the waste overlying the bedrock has resistivity of less than 10 Ωm, over which the resistivity increases, which corresponds well to the groundwater level as documented in boreholes elsewhere in the landfill. Some stratification in the resistivity is visible in the upper part, corresponding most likely to variation in water content in the waste material and a transition to a top cover of soil material. A zone with low resistivity at the surface is evident in the right part of the model, where the cover layer is missing. The inverted IP model is shown as normalised chargeability in Figure 2b. The volumes with high normalised chargeability are interpreted to consist of mixed waste or leakage contamination, whereas low chargeability volumes are interpreted as soil cover on top of the waste, soil barriers between waste cells and sedimentary rock below the waste respectively. The waste that is not covered by soil is clearly visible as high chargeability at the surface. High chargeability in the bottom part of the model may possibly be caused by chemical precipitation in connection with contaminant migration along the former stream channel.

a)



b)

Figure 2. 3D model from part of Filborna waste deposit; a) resistivity, b) normalised IP.

5. Discussion and Conclusions

The results show that resistivity is useful for characterising the distribution of different geological materials, and as indication of presence of water. In the St Hans Backar example the lowest resistivity correlates with a zone of seasonal leachate water outflow, and at Filborna the drop in resistivity coincides with groundwater levels in the landfill. The results, however, clearly illustrate that with the resistivity models alone it is difficult or impossible to outline where the waste is buried, and to discriminate between different types of material within the waste body. The addition of the IP results enhances the possibilities to discriminate between waste and geological materials, especially when presented as normalised chargeability. The examples clearly show that combined resistivity and IP investigation is a powerful tool for mapping buried waste and groundwater contamination. Measuring the IP in time domain with multi-channel multi-electrode equipment is time efficient, which is critical for the practical applicability of the technique. Since the IP data can only be entered as one integrated value in the inversion software used here the full information content of the IP data is not used, and new inversion approaches where the entire decay curve is inverted may potentially reveal more about for example the type of waste.

6. Acknowledgements

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7. References

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