MIKOVINY SÁMUEL DOCTORAL SCHOOL OF EARTH SCIENCES

Head of the Doctoral School:
Prof. Dr. Péter Szűcs, professor

# DELINEATION AND CHARACTERIZATION OF CONTAMINATED AREAS USING GEOPHYSICAL AND GEOSTATISTICAL METHODS

## PHD THESIS SUMMARY

**Written by:**
**MARCELL SZILVÁSI**
Earth Sciences Engineer

**Supervisors:**

**DR. ISTVÁN HAVASI**
associate professor

**† DR. HABIL. ENDRE TURAI**
private-docent

**University of Miskolc**
**Department of Geophysics**
**Miskolc**
**2026**

# 1. SCIENTIFIC BACKGROUND AND OBJECTIVES

Reclaimed landfills, as well as waste disposal sites constructed without compliance with modern regulations, may pose significant environmental risks; therefore, investigating their spatial extent, internal structure, and potential contaminant migration is of high importance. Traditional exploration methods (such as drilling and sampling) provide highly accurate information; however, they are spatially limited and costly, and in the case of landfills, it is not advisable to penetrate sealing layers. In contrast, geoelectrical geophysical methods provide a non-invasive solution for investigating subsurface conditions over large areas.

The combined use of multi-electrode resistivity surveys and induced polarization (IP) is widely applied in landfill and environmental investigations because these methods are sensitive to petrophysical contrasts between the waste body, leachate-affected zones, and natural geological formations (Bernstone et al., 2000; Cardarelli and Di Filippo, 2004; Chambers et al., 2006; Guinea et al., 2022). I selected the IP method specifically because it is particularly suitable for detecting biogeochemically active and contaminated zones, as polarization effects are closely related to the electrochemical properties of the subsurface medium (Flores-Orozco et al., 2020; Chao et al., 2024).

One of the main challenges of geoelectrical data interpretation is that the results are often ambiguous, and the separate evaluation of individual parameters does not necessarily lead to a unique geological model. Classical interpretation approaches are typically based on individual 2D profiles, which are only partially suitable for revealing spatial relationships. The international literature demonstrates that the joint processing and spatial integration of multiple profiles arranged in a structured geometry significantly improves the interpretation of landfill structures and contaminated zones (Maurya et al., 2017; Martorana et al., 2023).

Time-domain IP data were processed to separate different polarization mechanisms using time constant spectra (TAU transformation) (Turai, 1981). However, the resulting multiparameter datasets require complex statistical interpretation. Geoelectrical datasets are often non-Gaussian and contain outliers; therefore, I applied robust statistical methods. I used the Steiner-type Most Frequented Value (MFV) method, which is suitable for the stable determination of dominant values in heterogeneous datasets.

My main objective was to develop a complex, multiparameter geoelectrical interpretation framework that is suitable for the reliable characterization of reclaimed landfills and other near-surface contaminated areas. I extended conventional geoelectrical processing steps with new and further developed methods. To achieve this objective, I:

- applied and adapted the Steiner-type MFV method to geoelectrical data, and I investigated different parameterization approaches,
- analyzed induced polarization data using time constant spectrum-based (WAV) processing,
- developed a topography-dependent horizontal slicing method that ensures the spatial integration of 2D profile data,
- and applied multivariate statistical methods (cluster analysis) to support interpretation.

I validated the developed methodology through several case studies, with particular emphasis on a reclaimed landfill located near Nyékládháza. By combining multi-electrode geoelectrical and induced polarization surveys with spatial integration, I was able to delineate the waste body and the potentially contaminated zones in a quasi-three-dimensional manner. In this thesis booklet, I present the methodological results only from this study area. My goal was not only to present a specific case study, but also to develop a generalizable multiparameter interpretation framework that contributes to increasing the reliability of environmental geophysical investigations and reducing interpretational uncertainty.

## 2. APPLIED METHODS AND RESULTS

I developed and applied a methodological framework aimed at the integrated, multiparameter interpretation of multi-electrode geoelectrical and induced polarization data. The processing workflow consists of several consecutive steps, ranging from field surveys to statistical interpretation.

### 2.1. Field Surveys and Inversion Processing

I carried out multi-electrode geoelectrical surveys, during which I recorded apparent resistivity and induced polarization data. I performed the surveys along a systematically arranged profile network, which ensured the possibility of spatial integration.

I processed the measured data using 2D inversion methods, which resulted in resistivity and chargeability models. I considered the topographic conditions (figure 1) during the inversion; therefore, I interpreted the resulting models in a spatially consistent manner.

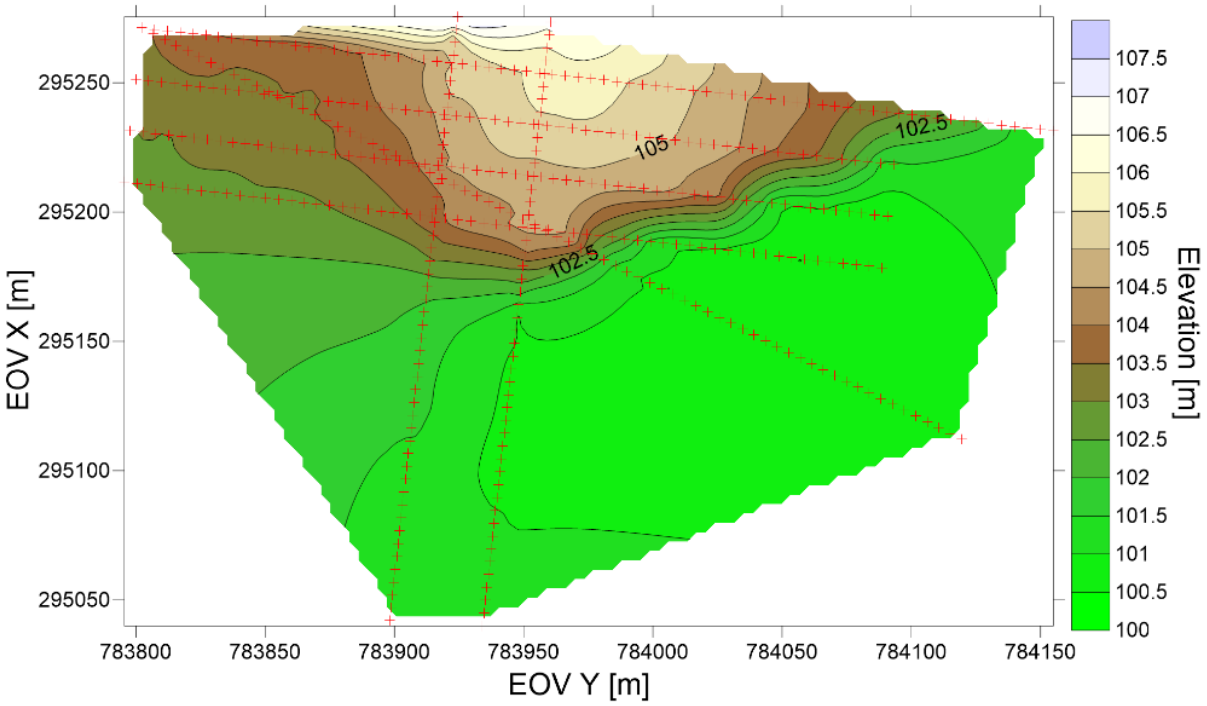

***Figure 1**: Topographic map of the study area with electrode locations marked by red crosses. (edited by the author)*

### 2.2. Spatial Integration of 2D Profiles

I integrated the inversion results obtained from individual 2D profiles into a unified spatial coordinate system. The resulting 2.5D dataset allowed me to compare and interpret different profiles together. This approach provides a spatial representation of the investigated structure without applying full 3D inversion, which is particularly advantageous under complex field conditions.

### 2.3. Horizontal Slicing Method

To support spatial interpretation, a horizontal slicing procedure was applied. In areas with varying topography, points corresponding to identical inversion levels are not located in a single horizontal plane; therefore, I developed a method (Figure 2/B) that defines slicing depths by taking electrode spacing and point density into account.

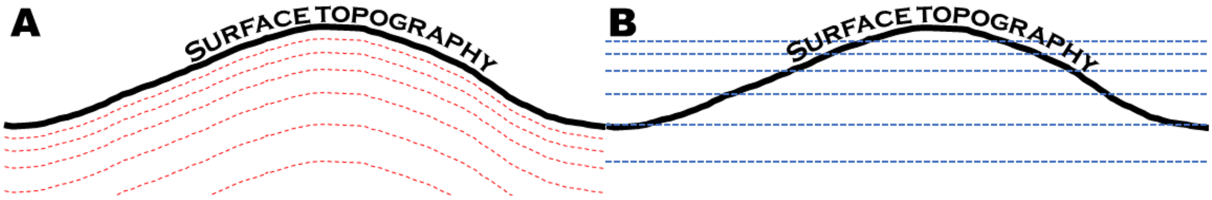

***Figure 2**: Effect of topography on horizontal slicing. (A) Distribution of calculated geoelectrical parameter points beneath a variable surface. (B) Horizontal planes defined by the proposed slicing algorithm. (edited by the author)*

This procedure ensures that the resulting horizontal maps represent consistent depth levels, which resulted in physically meaningful spatial interpretation. The horizontal distributions of resistivity (Figure 3) and induced polarization (Figure 4) clearly show that the spatial extent and structural heterogeneity of the waste body vary with depth.

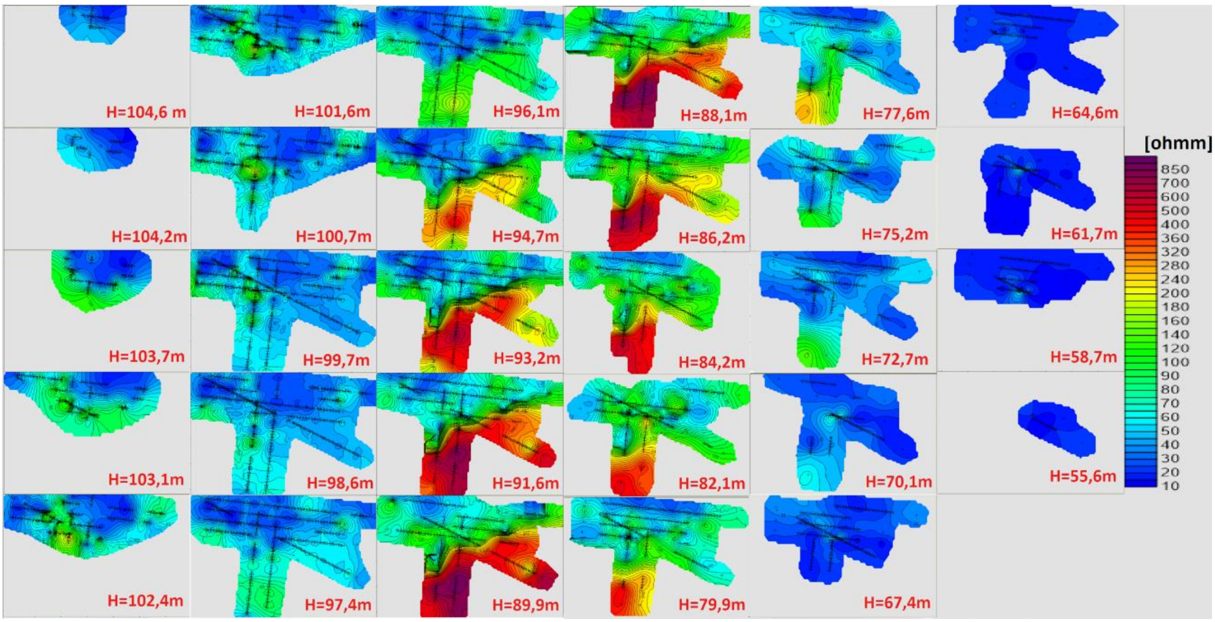

***Figure 3:** Horizontal resistivity maps at different elevation levels. (edited by the author)*

While resistivity primarily highlights conductivity contrasts, induced polarization is more sensitive to potentially contaminated and biogeochemically active zones.

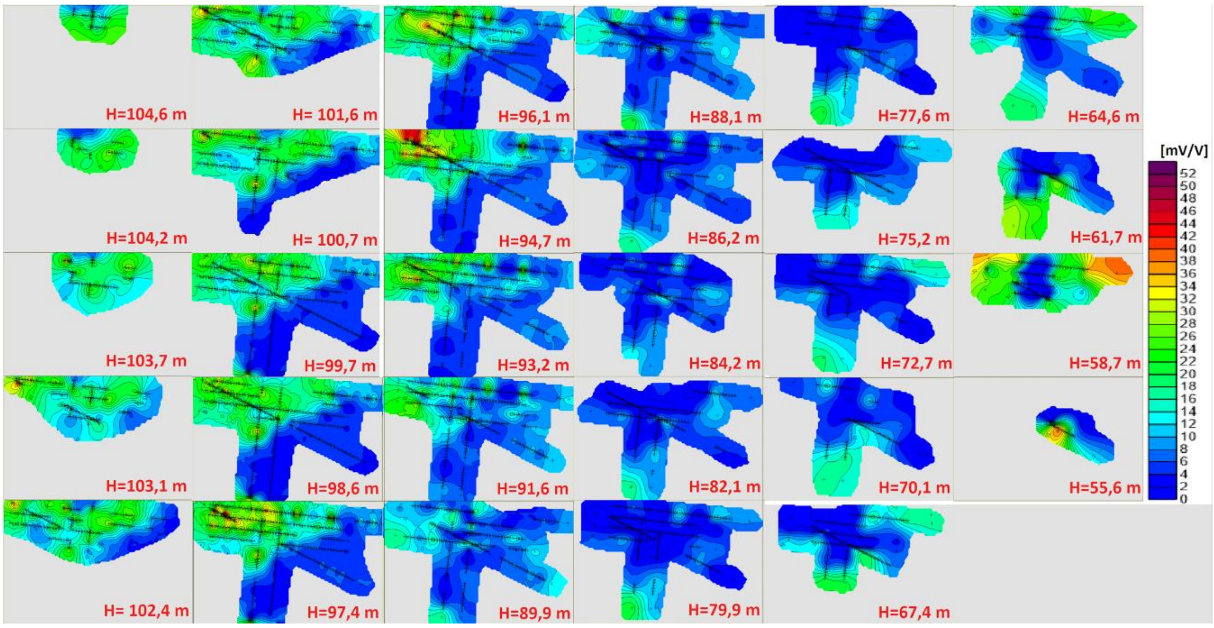

***Figure 4:*** *Horizontal chargeability maps of induced polarization at different elevation levels. (edited by the author)*

The effect of the developed slicing procedure was also evaluated quantitatively. To compare the original and the new slicing system, the layer indexes were normalized and the difference in the relative slice positions of the points was determined. In the studied area, the average difference was 1.17 layers and the median was 0.86 layers, which shows that the procedure rearranges the majority of the points only to a small extent, while eliminating the geometric distortions resulting from the topography. This proves that the method does not distort the spatial interpretation, but rather improves its physical consistency.

## 2.4. WAV-Based Induced Polarization Processing

To achieve a more detailed interpretation of induced polarization data, I applied time constant spectrum-based (WAV) processing. This method separates different polarization mechanisms and improves the physical interpretation of subsurface processes. By applying this method, I identified subtle structural and material differences (Figure 5) that were not clearly distinguishable using conventional parameters.

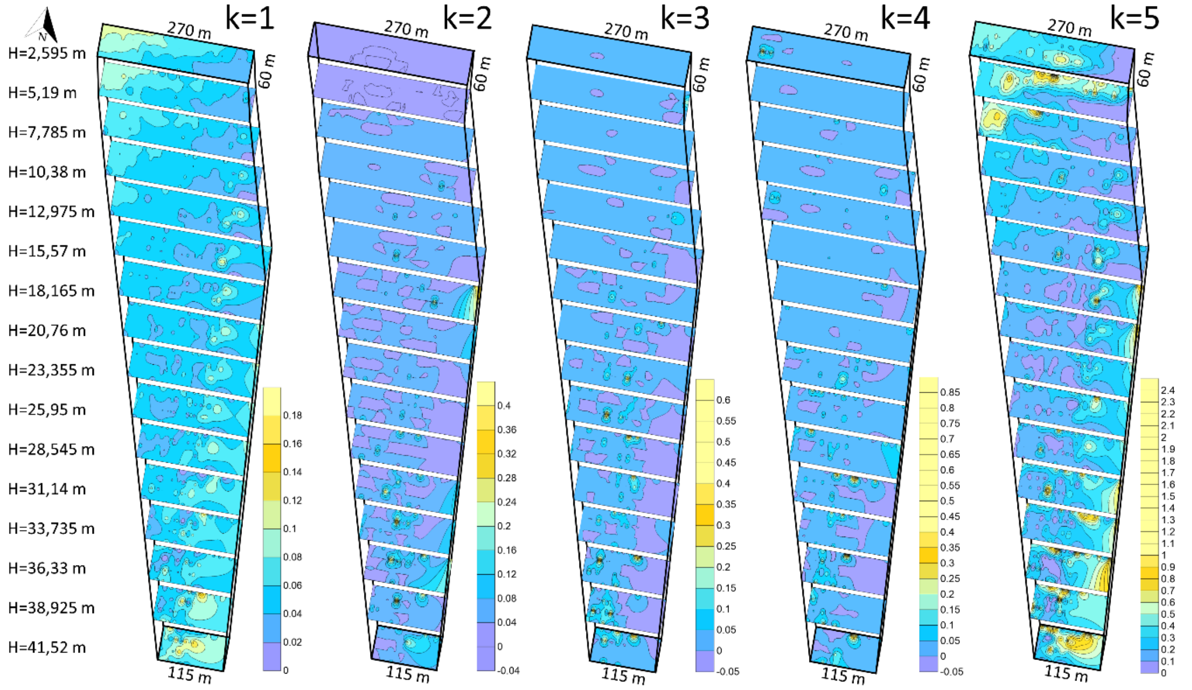

***Figure 5:*** *2D horizontal sections of the normalized WAV parameter corresponding to the shortest relaxation time range (k = 1-2), the intermediate relaxation time range (k = 3–4), and the longest relaxation time range (k = 5), at different reference levels along profiles Ny1–4. (edited by the author)*

### 2.5. MFV-Based Statistical Processing

To ensure robust interpretation of geoelectrical data, I applied the Steiner-type Most Frequented Value (MFV) method. This method is suitable for determining dominant values in datasets that are non-Gaussian and contain outliers. I applied two approaches:

- classical Steiner MFV method,
- MFV calculated with a fixed dihesion parameter.

I concluded that different parameterizations result in different spatial sensitivities, which supports adaptive interpretation. The iterative Steiner MFV method (Figure 6/B) identifies dominant values in vertical data columns more effectively. This is also reflected in the extent of the color scale, as the results cover the full 0–400 Ωm range, indicating a wider dynamic range of dominant values. In contrast, the MFV calculated with a fixed *ε* parameter (Figure 6/A) emphasizes values closer to the mean; however, by filtering out outliers, it still provides more robust results than conventional averaging.

I also investigated the effect of sampling density. I found that excessively dense sampling (5×5 m) results in spatially inconsistent patterns, where intersecting profiles highlight different dominant values in the same area. This effect is still present at 10×10 m spacing, although to a lesser extent. At 20×20 m sampling density, I obtained stable and spatially consistent results. This demonstrates that sampling density is not only a resolution issue but also an interpretational stability factor.

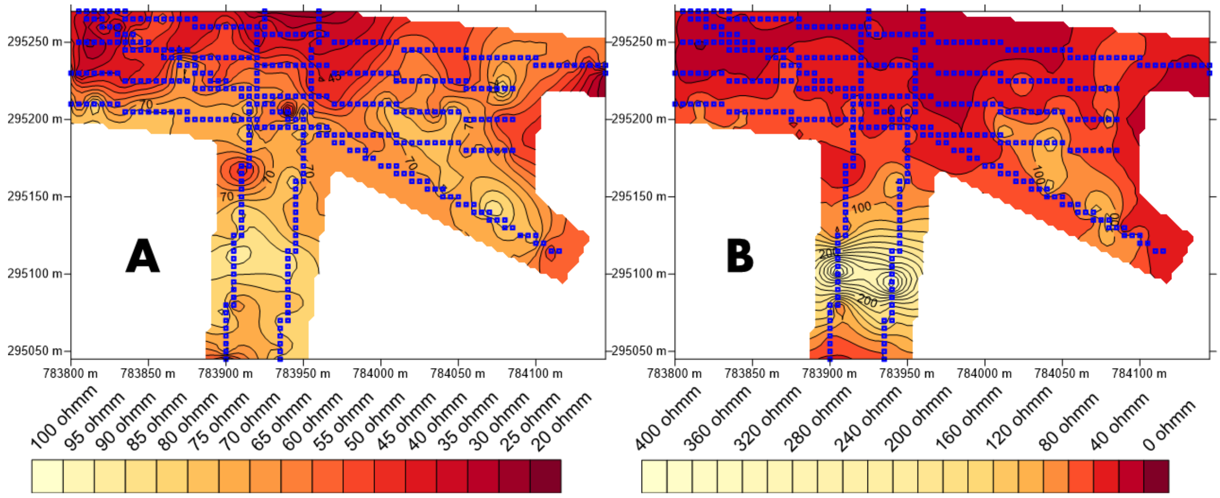

***Figure 6:*** *Resistivity maps using MFV with fixed ε (A) and iteratively recalculated ε (B), where the blue squares indicate reference points. (edited by the author)*

The spatial effect of applying the iteratively recalculated ε parameter can be clearly illustrated by comparing different sampling densities (Figure 7).

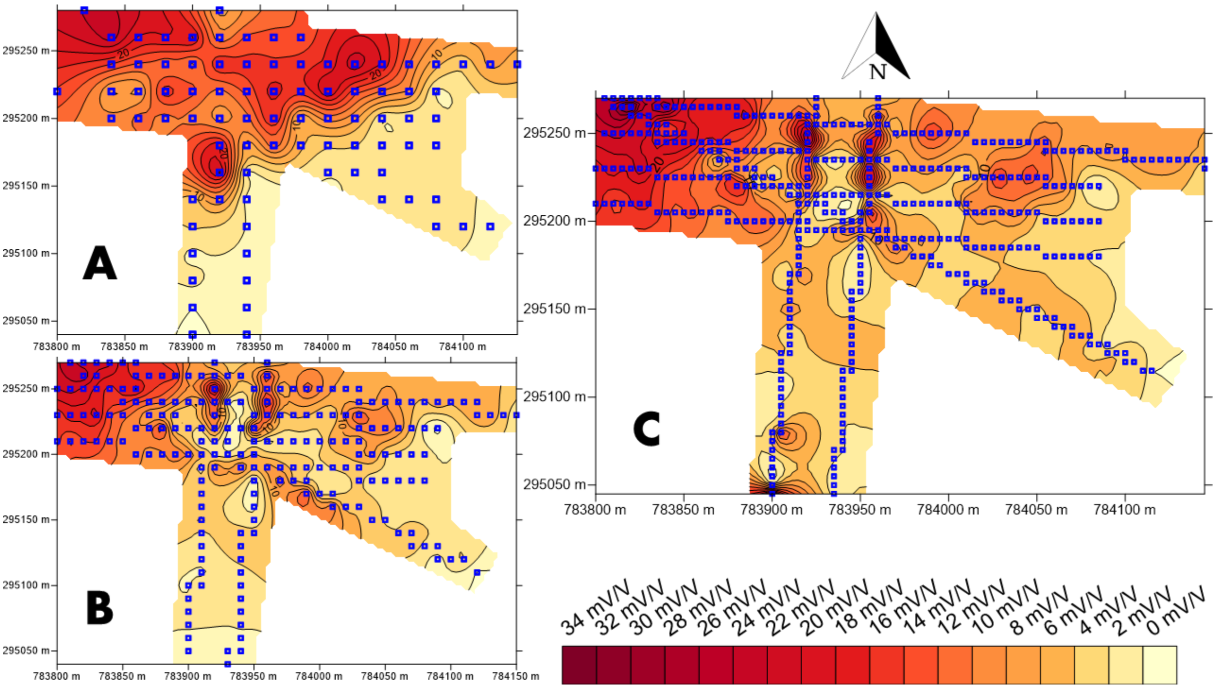

***Figure 7:*** *Induced polarization maps using MFV with iteratively recalculated ε, where the blue squares indicate reference points. A: 20×20 m zones; B: 10×10 m zones; C: 5×5 m zones. (edited by the author)*

In the case of excessively dense sampling with a 5×5 m resolution, intersecting profiles designate different most frequent values in the same areas, resulting in a spatially incoherent pattern. This phenomenon can also be observed at a 10×10 m resolution, although to a lesser extent. In contrast, a sampling density of 20×20 m already provides sufficiently stable and spatially consistent results, which can be considered an optimal compromise from the perspective of the practical applicability of the method. This highlights that sampling density is not only a matter of data resolution, but also of interpretational stability.

In the studied area, based on the quantitative comparison, in the case of resistivity, the MFV method calculated with the iterative ε-parameter showed a higher relative deviation (~24–27%) and a lower standard deviation (~16–21%) than the fixed ε-parameter version (~20–24% and ~22–25%), while in the case of excited polarization, the behavior of the method depended on the sampling density.

## 2.6. Cluster Analysis

To support the interpretation of the multiparameter dataset, I applied cluster analysis. This method groups spatial units with similar properties based on statistical criteria. I used this approach to reduce subjectivity in visual interpretation and to provide a more structured basis for distinguishing geological and environmental units.

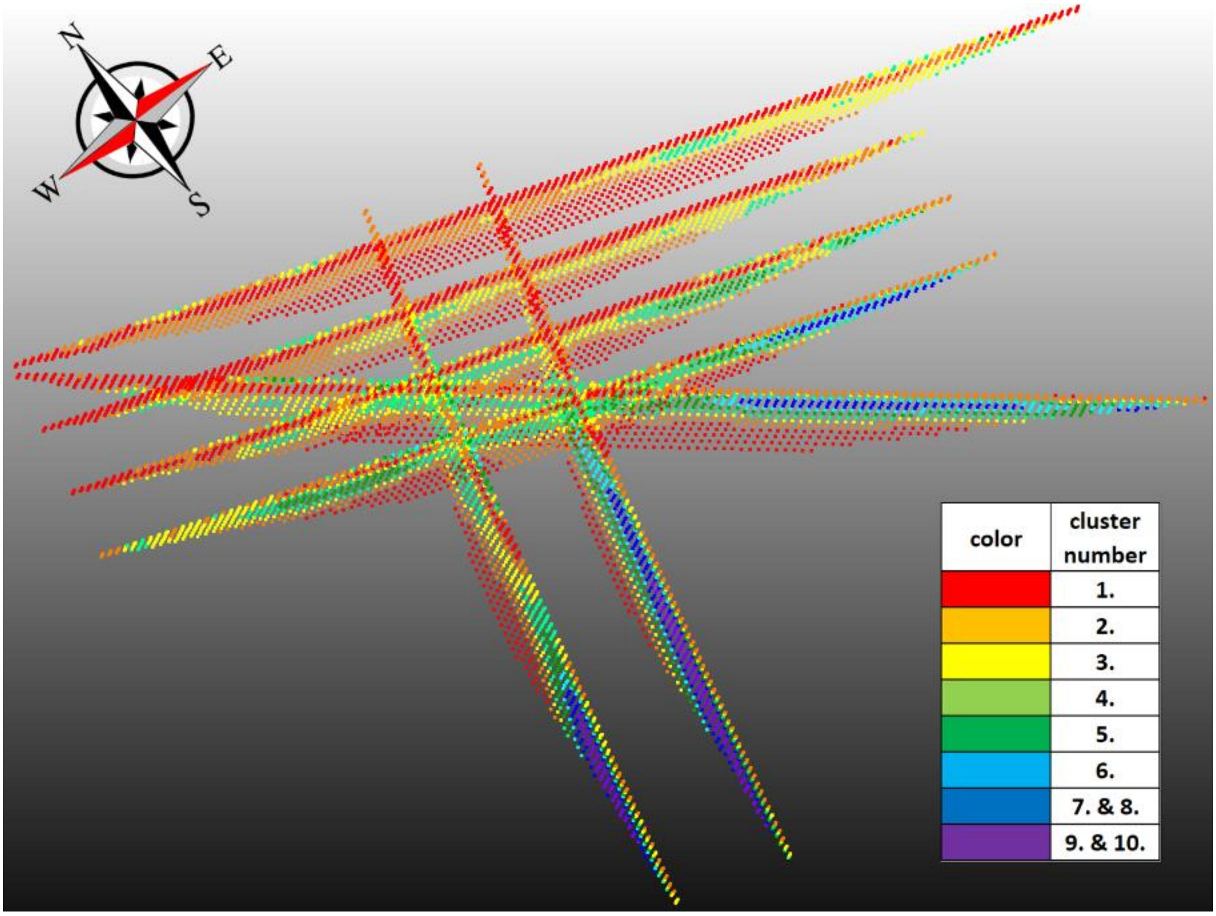

***Figure 8:*** *Spatial distribution of measurement points classified into 10 clusters. (edited by the author)*

My results show that cluster analysis supports the separation of the waste body, potentially contaminated zones, and background areas; however, I also demonstrated that boundary delineation still requires expert interpretation. Therefore, I interpret clustering as a supporting statistical tool rather than a fully objective classification method.

## 2.7. Basement and Thickness Maps

Based on resistivity and induced polarization models, I determined the lower boundary of the waste body and the potentially contaminated zones. From these surfaces, I derived thickness maps and volume estimates.

My results show that the average thickness of the waste layer is 4–8 m, locally reaching up to 13 m, while the potentially affected zone exhibits a larger spatial extent.

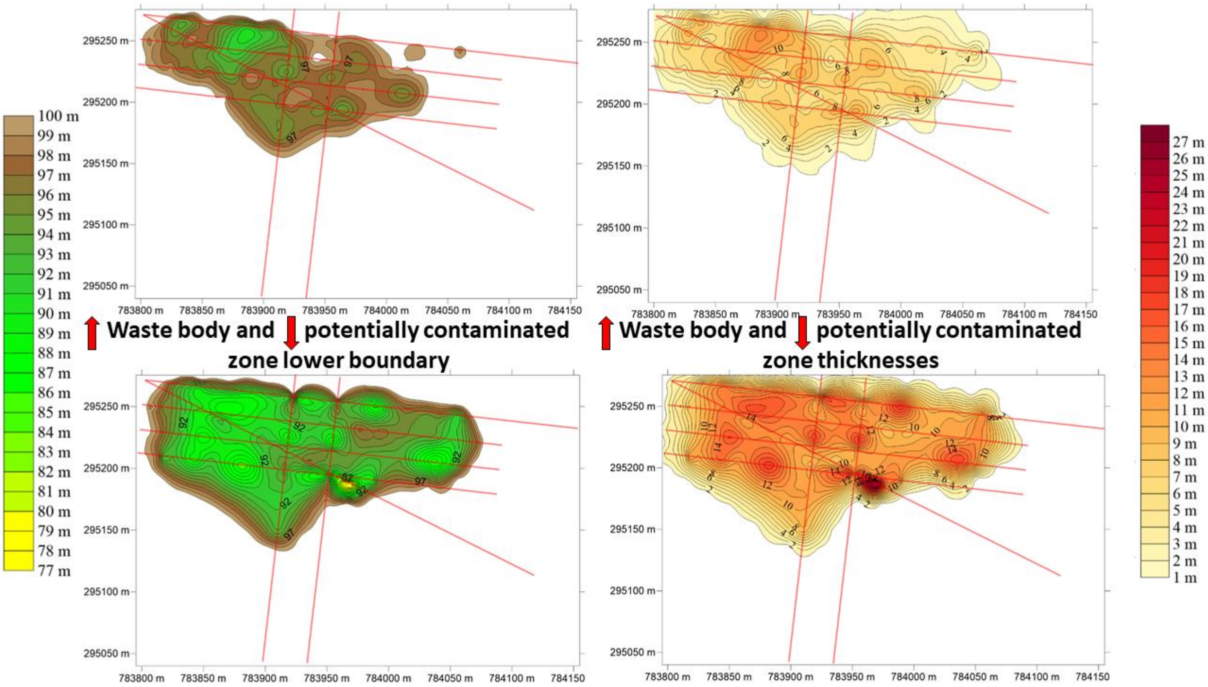

***Figure 9:** Contour maps of the estimated lower boundary of the waste body and the potentially contaminated zone [m above Baltic Sea level], as well as contour maps of their estimated thicknesses [m]. Red lines indicate the locations of the geoelectrical measurement profiles. (edited by the author)*

## 2.8. Integrated Interpretation

The combined application of the applied methods ensured the complex, multiparameter interpretation of the investigated area. I analyzed the spatial distribution of resistivity and induced polarization, and by complementing this with the horizontal slicing procedure, I ensured the geometric delineation of the waste body. I applied MFV-based statistical processing to robustly highlight the dominant physical characteristics, while I used WAV-based processing to reveal finer structural and material differences of the polarization processes. I applied cluster analysis to perform the statistical grouping of the multiparameter dataset, which supported the separation of different structural units; however, I also demonstrated that their final delineation still requires expert interpretation.

I obtained the integrated results from the different methods, so I was able to delineate the spatial distribution of the waste body, the potentially contaminated zones, and the unaffected background areas. The individual processing steps did not operate independently; instead, they reinforced each other, which significantly reduced inversion and interpretation uncertainties and improved the consistency of the results.

I summarized the operation of the methodological framework and the relationships between the individual procedures in Figure 10. The figure highlights that the sequential application of the different processing steps results in a structured, multi-phase interpretation workflow, in which statistical and geophysical methods complement each other in order to support the reliable investigation of complex near-surface systems. This integrated approach is not only applicable in the present study, but can also be used in general environmental geophysical problems, especially in heterogeneous and complex near-surface environments.

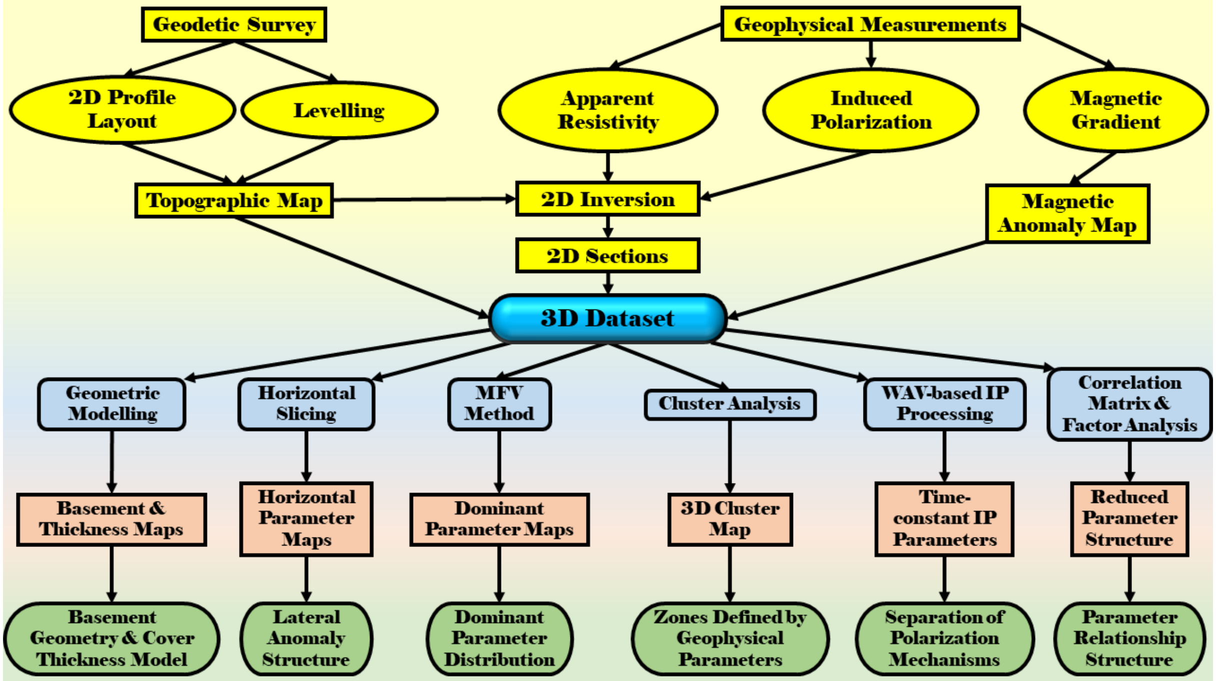

***Figure 10:*** *Integrated result of the applied geoelectrical methodological framework. (edited by the author)*

## 3. NEW SCIENTIFIC RESULTS

### Thesis 1

I demonstrated that the behavior of the Steiner-type Most Frequented Value (MFV) method in geoelectrical datasets depends on the coefficient of variation (CV), and that the applied $\varepsilon$-parameterization together with sampling density jointly determines the stability of the results and the identification of dominant values.

Elaboration of the thesis:

In applying the MFV method, I compared the obtained parameter values to the mean values determined at the reference points. I interpreted the relative deviation as a measure of departure from the distorting effect of the mean, while I used its standard deviation to characterize the stability of the method.

From my investigations, I found that in datasets with relatively higher coefficients of variation (e.g., resistivity, CV ≈ 1.34), the MFV method operating with an iteratively recalculated $\varepsilon$-parameter yielded, in every examined case, a larger relative deviation (~24–27%) and a smaller standard deviation (~16–21%). This indicates a more stable and less biased determination of dominant values.

In datasets with relatively lower coefficients of variation (e.g., induced polarization, CV ≈ 0.73), the MFV parameterization proved to be more sensitive to sampling density. Under dense sampling, the version calculated with a fixed $\varepsilon$-parameter produced more stable results, whereas under sparser sampling (20 × 20 m), the approach based on an iterative $\varepsilon$-parameter became more reliable. In data systems with lower relative dispersion, the stable application of the method requires a higher degree of spatial aggregation.

I established that the applicability of the MFV method depends not only on the distribution of the data, but also on their relative dispersion. In high-variance systems, iterative $\varepsilon$-parameterization provides stable results directly, whereas in low-variance systems, ensuring stability requires the joint optimization of sampling density and parameterization.

### Thesis 2

I demonstrated that time constant spectrum-based (WAV) processing of induced polarization data, complemented by dominance analysis based on standardized parameters, can be effectively applied in geoelectrical investigations. The procedure enables the quantitative separation of spatial patterns associated with different polarization mechanisms.

Elaboration of the thesis:

During WAV-based processing, I decomposed the decay curves of induced polarization into distinct time constant spectra, and I showed that the components corresponding to different time windows exhibit different spatial distributions. I confirmed that the method can be applied not only on vertical sections but also on horizontal slices, thereby allowing the investigation of the spatial extent of polarization phenomena.

To ensure comparability between different time constant ranges, I standardized the WAV parameters relative to the distribution within each time window, and I determined the dominant time constant range for each spatial point. In the investigated area, short time constants ($k = 1$–$2$) dominated approximately 74% of the points, while the long-time constant component ($k = 5$) appeared as dominant in nearly 17% of the points. Medium time constants ($k = 3$–$4$) occurred less frequently and were typically confined to localized zones.

Short time constants are primarily associated with background processes, whereas medium and long-time constants form spatially distinct and structured zones. The responses related to long time constants show extended and vertically continuous patterns, which can be linked to persistent electrochemical and biogeochemical processes, as well as to the presence of contaminants.

I established that the standardized dominance analysis is suitable not only for the investigated study area but also in a general methodological sense for comparing the relative spatial role of different time constant ranges. At the same time, the specific proportions of dominance depend on the given geological and contamination conditions.

**Thesis 3**

I developed and applied a topography-corrected horizontal slicing approach that provides a consistent spatial interpretation for geoelectrical section points located at different elevations under variable surface conditions.

Elaboration of the thesis:

In the procedure I developed and organized the points of the geoelectrical sections into horizontal slices by explicitly accounting for real topographic conditions, thereby enabling a unified spatial interpretation of profiles located at different elevations.

To quantify the effect of the method, I normalized the layer indices of the original and the modified slicing systems, then determined the differences in relative slice positions point by point, and finally rescaled these differences to the levels of the original system.

In the investigated area, the mean difference was 1.17 layers, the median was 0.86 layers, and the maximum difference reached 4.14 layers.

Within the validation area, the procedure caused only minor rearrangements in the vertical structure for the majority of points, while at the same time correcting distortions related to topography. Larger deviations primarily appeared in sections characterized by more pronounced surface variability, reflecting the sensitivity of the method to actual geometric conditions.

I established that the topography-corrected slicing procedure modifies the data arrangement in a geometrically consistent and quantitatively controlled manner in the investigated area, thereby providing a more reliable spatial interpretation under variable surface conditions.

### Thesis 4

I demonstrated that the processing of multiparameter geoelectrical data using cluster analysis can be applied to the objective separation of spatial domains with different geophysical properties, provided that the number of clusters is determined through the combined use of quantitative validation (silhouette index) and geophysical interpretation.

Elaboration of the thesis:

During my investigations, I showed that cluster analysis is an effective tool for structuring multiparameter datasets defined by the joint consideration of resistivity and induced polarization, and that it allows the separation of geophysical domains. I found that the clustering result is strongly influenced by the choice of the number of clusters: at low cluster numbers, the system becomes overly aggregated, whereas at high cluster numbers, an artificial partitioning of the parameter space appears, along with the formation of clusters containing only a few elements.

Through quantitative evaluation across different cluster numbers, I established that the silhouette index provides a suitable measure for the objective characterization of clustering quality and clearly indicates the optimal range of cluster numbers. Although higher cluster numbers are less favorable from a statistical perspective, they support a more detailed exploration of the parameter space, which can be justified from an interpretational point of view.

I conclude that cluster analysis cannot be regarded as a fully automated method. At the same time, when combined with quantitative validation and geophysical interpretation, it reduces subjectivity and provides an effective means for exploring the spatial structure of geoelectrical data.

**Thesis 5**

I developed and applied an integrated geoelectrical data processing and interpretation framework that reduces interpretational uncertainty in the given study environment through the sequential application of interdependent processing steps.

Elaboration of the thesis:

In my methodological framework, I link survey design, inversion, slicing, and statistical processing into a coherent interpretation system. I demonstrated that the sequential use of these processing steps leads to more consistent spatial models.

In its present form, the integration relies on statistical approaches, which also points to further development potential, particularly toward joint inversion methodologies.

## 4. PRACTICAL APPLICABILITY

The practical significance of the methodological framework presented in this dissertation primarily lies in near-surface environmental geophysical investigations, particularly in reclaimed landfills and other contaminated areas. I applied the integrated use of multi-electrode geoelectrical and induced polarization surveys to investigate subsurface structures in a non-invasive and cost-effective manner, providing an alternative to traditional point-based exploration methods.

A key practical advantage of the developed approach is that I integrated several complementary processing steps into a unified interpretation system. By spatially integrating 2D inversion profiles and applying the horizontal slicing procedure, I achieved quasi-three-dimensional characterization of the investigated object without requiring a full 3D measurement and inversion system. This is particularly advantageous where field conditions or infrastructure limit the installation of a regular electrode array.

By applying robust statistical methods, particularly MFV-based processing, I improved the reliability of geoelectrical data interpretation by reducing the influence of outliers and noise. This results in more stable and reproducible outcomes, which are essential for engineering decision support. I also applied cluster analysis to reduce subjectivity in interpretation by enabling the separation of spatial units with different physical properties.

Using time constant spectrum-based processing of induced polarization data (WAV method), I obtained additional information about the electrochemical properties of the subsurface medium. The method is sensitive to contaminants and biogeochemical processes, allowing more accurate delineation of potentially contaminated zones. In practice, the presented methodological framework can be applied in the following fields:

- assessment and monitoring of reclaimed and active landfills,
- delineation and risk assessment of contaminated areas,
- engineering geophysical preliminary investigations (e.g., before construction projects and infrastructure development),
- and spatial modelling of heterogeneous subsurface structures.

By combining different processing steps, I reduced interpretational uncertainty arising from ambiguity, making the results more directly applicable in engineering and environmental decision-making. I demonstrated that the integrated geoelectrical interpretation approach presented in this dissertation represents not only a scientific advancement but also a practical tool for investigating complex near-surface problems.

## 5. PUBLICATIONS RELATED TO THE TOPIC IN CHRONOLOGICAL ORDER

[1] **Szilvási, M. és Havasi, I. (2026):** Rekultivált hulladéklerakó térbeli lehatárolása multielektródás geoelektromos és gerjesztett polarizációs mérések alapján. *Magyar Geofizika* ISSN: 0025-0120 67. évfolyam (2026) 1. szám

[2] **Szilvási, M. (2026):** Application of the Most Frequented Value Method in Geoelectrical Data System. *Geosciences an Engineering* ISSN: 2063-6997 Vol. 14 No. 1 (2026)

[3] **Szilvási, M. (2025):** New methods for processing geoelectric geophysical survey data of shallow-depth contaminants and man-made facilities. *LV. Meeting of Young Geoscientists/Ifjú Szakemberek Ankétja.* pp. 48-49.

[4] **Szilvási, M. (2025):** A geodézia támogató szerepe begyűjtött geofizikai adatok feldolgozásánál. In: *LXIII. Bányamérő Konferencia: "Technológiaváltás a bányamérésben"* pp. 96-102.

[5] **Szilvási, M. (2025):** Paraméterérzékenységi vizsgálatok különböző elektróda elrendezések esetén. *Új eredmények a műszaki föld- és környezettudományban 2025.* pp. 99-112.

[6] **Szilvási, M. (2023):** Horizontális szeletelési módszer geofizikai geoelektromos szelvényezéshez. *Új eredmények a műszaki föld- és környezettudományban 2023.* pp. 168-175.

[7] **Szűcs, P., Turai, E., Mádai, V., Vass, P., Miklós, R., Zákányi, B., Ilyés, Cs., Fekete, Zs., Kilik, R., Móricz, F., Nyíri, G., Szilvási, M. és Szabó, N. P. (2022):** Innovation in assessment of the geothermal energy potential of abandoned hydrocarbon wells in the southern and southeastern foreground of the Bükk Mountains, northeast Hungary *Hydrogeology Journal*, 30(8), pp. 2267-2284. https://doi.org/10.1007/s10040-022-02560-y

[8] **Szilvási, M. (2022):** Shallow geophysical premeasurements at a construction site. *Inverziós Ankét 2022 Konferencia*. 31 p.

[9] **Szilvási, M. és Turai, E. (2018):** Geodéziai alapok kialakítása egy rekultivált hulladéklerakó geofizikai felméréséhez és kiértékeléséhez. In: LVII. Bányamérő Továbbképző és Tapasztalatcsere. pp. 56-61.

[10] **Turai, E., Nádasi, E. és Szilvási, M. (2018):** Felszín alatti objektumok és földtani szerkezetek kutatása geoelektromos tomográfiával. *Műszaki Tudomány az Észak-Kelet Magyarországi Régióban 2018* pp. 374-381.

[11] **Turai, E., Szilvási, M., Nádasi, E. és Abordán, A. (2017):** Rekultivált hulladéklerakó belső szerkezetének vizsgálata geoelektromos módszerekkel. *Műszaki Tudomány az Észak-Kelet Magyarországi Régióban 2017* pp. 586-593.

[12] **Szilvási, M., Turai, E. és Nádasi, E. (2017):** Resistivity and IP Monitoring near a Tailings Storage - A Case Study from Hungary In: *79th EAGE Conference & Exhibition 2017* Paris, Paper Th SP2 05, 3 p.

[13] **Turai, E. és Szilvási, M. (2017):** Rekultivált hulladéklerakó szennyezettségének vizsgálata. *Műszaki Földtudományi Közlemények*, 86(1) 181-192.

[14] **Szilvási, M., Turai, E. és Kovács, B. (2016):** In Field Geoelectric Measurements for Detection of Heavy Metal Contaminations. microCAD International Multidisciplinary Scientific Conference, Paper: A12

[15] **Turai, E., Nádasi, E. és Szilvási, M. (2016):** A geoelektromos geofizikai módszerek terepi alkalmazásának új eredményei a környezetvizsgálatok területén. *Műszaki tudomány az Észak-Kelet Magyarországi régióban 2016* pp. 680-689.

[16] **Szilvási, M., Turai, E. és Kovács, B. (2016):** Heavy metal detection using geoelectric methods in field. *XLVII. Ifjú Szakemberek Ankétja – Meeting of Young Geoscientists* pp. 57-58.

## REFERENCES OF THE THESIS

[1] Bernstone, C., Dahlin, T., Ohlsson, T., Hogland, W. (2000): DC-resistivity mapping of internal landfill structures: two pre-excavation surveys. *Environmental Geology*, 39(3–4), 360–371. https://doi.org/10.1007/s002540050015

[2] Cardarelli, E., Di Filippo, G. (2004): Integrated geophysical surveys on waste dumps: evaluation of physical parameters to characterize an urban waste dump (four case studies in Italy). *Waste Management & Research*, 22(5), 390–402. https://doi.org/10.1177/0734242X04046042

[3] Chambers, J. E., Kuras, O., Meldrum, P. I., Ogilvy, R. D., Hollands, J. (2006): Electrical resistivity tomography applied to geologic, hydrogeologic, and engineering investigations at a former waste-disposal site. *Geophysics*, 71(6), B231–B239. https://doi.org/10.1190/1.2360184

[4] Chao, C., Ma, X., Liu, S., Zheng, C., Mao, D. (2024): Characterization of solid waste deposit using electrical resistivity tomography and time-domain induced polarization. *Journal of Environmental Management*, 366, 121854. https://doi.org/10.1016/j.jenvman.2024.121854

[5] Flores-Orozco, A., Gallistl, J., Steiner, M., Brandstätter, C., Fellner, J. (2020): Mapping biogeochemically active zones in landfills with induced polarization imaging: The Heferlbach landfill. *Waste Management*, 107, 121–132. https://doi.org/10.1016/j.wasman.2020.04.001

[6] Guinea, A., Bicknell, J., Cox, N., Swan, H., Simmons, N. (2022): Characterization of legacy landfills with electrical resistivity tomography: a comparative study. *Journal of Applied Geophysics*, 203, 104716. https://doi.org/10.1016/j.jappgeo.2022.104716

[7] Martorana, R., Capizzi, P., Pirrera, C. (2023): Unconventional arrays for 3D electrical resistivity and induced polarization tomography to detect leachate concentration in a waste landfill. *Applied Sciences*, 13(12), 7203. https://doi.org/10.3390/app13127203

[8] Maurya, P. K., Rønde, V. K., Fiandaca, G., Balbarini, N., Auken, E., Bjerg, P. L., Christiansen, A. V. (2017): Detailed landfill leachate plume mapping using 2D and 3D electrical resistivity tomography – with correlation to ionic strength measured in screens. *Journal of Applied Geophysics*, 138, 1–8. https://doi.org/10.1016/j.jappgeo.2017.01.019

[9] Turai, E. (1981): GP time-domain görbék TAU-transzformációja. *Magyar Geofizika*, 22(1), 29–36. ISSN: 0025-0120