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# Soil physical properties evaluation from geophysical and remote sensing datasets

***Abstract**. The present study highlights the possibility of assessing soil physical properties using geophysical and hyperspectral imaging techniques as leverage on the conventional approach of soil survey characterized by some pitfalls. Randomly selected farmlands where the in-situ nature of the soil is still preserved were utilized for the field data acquisition. This was preceded by the numerical modelling of the response of the soil to one of the adopted methods of study to ascertain the possible depth of investigation and field data acquisition parameters. Results of field data analysis enabled the delineation of the subsurface horizons of the soil at the test sites which at the same time allows both the qualitative and quantitative evaluation of some physical properties such as porosity, bulk density, and some state variables such as the volumetric water contents and the compactness of the soil.*

***Streszczenie.** Niniejsze badanie podkreśla możliwość oceny właściwości fizycznych gleby przy użyciu technik obrazowania geofizycznego i hiperspektralnego jako dźwigni konwencjonalnego podejścia do badania gleby, charakteryzującego się pewnymi pułapkami. Losowo wybrane grunty rolne, na których nadal zachowana jest natura gleby in situ, zostały wykorzystane do pozyskania danych terenowych. Poprzedziło to numeryczne modelowanie reakcji gleby na jedną z przyjętych metod badania w celu ustalenia możliwej głębokości badania i parametrów pozyskiwania danych terenowych. Wyniki analizy danych terenowych umożliwiły określenie poziomów podziemnych gleby w miejscach testowych, co jednocześnie pozwala na jakościową i ilościową ocenę niektórych właściwości fizycznych, takich jak porowatość, gęstość objętościowa i niektóre zmienne stanu, takie jak objętościowa zawartość wody i zwartość gleby. **(Ocena właściwości fizycznych gleby na podstawie geofizycznych i teledetekcyjnych zbiorów danych)***

**Keywords:** Soil, physical properties, geophysical and hyperspectral data.
**Słowa kluczowe:** Gleba, właściwości fizyczne, dane geofizyczne i hiperspektralne.

## Introduction

The importance of soil in the ecosystem cannot be over-emphasized. It is what the plants depend upon to derive their nutrients, animals as well indirectly depend on it by grazing on the plants that grow on it. Various tasks of living creatures that amount to different aspects of life including multiplication and extinction, and negative environmental processes directly or indirectly relate to it [1]. Thus, the continuous assessment and understanding of the soil characteristics should be sustained. Common soil surveys are found to be hinged on the evaluation of the field morphology of soil profiles and are largely by visualizations and few field tests [2]. Several conventional soil assessment techniques are available and well documented in the literature [3, 4, 5], but some pitfalls characterize them. These include, the concealing nature of soil subparts makes thorough investigation cumbersome. The traditional methods of soil survey are expensive and time-consuming. Thus, the reliability of the outcome of these approaches to soil assessment cannot be guaranteed. On this premise is the conceptualization of the alternative approach that can mitigate the aforementioned gaps in soil assessment. Such an alternative approach can be found in the use of geophysical and remote sensing methods of survey. Geophysical methods of survey involve the application of the principle of physics to studying the earth's surface using various forms of sensors and thus allow investigation of hidden subsurface media. There are different methods of geophysical survey depending on the physical quantity sought to evaluate. Of the various types of geophysical methods, electromagnetic conductivity (EMC) and ground penetrating radar (GPR) which utilizes electromagnetic pulse energy in the range of 10 MHz to 4 GHz [6] have been selected for this study. The choice of the methods is due to non-invasiveness, fast, and the possibility for continuous and repeated measurement which could ameliorate the gaps in the conventional soil survey methods. Hyperspectral imaging techniques – a remote sensing method was also integrated with the geophysical methods with a view to control and substantiate their results. Implementations of geophysical techniques in soil investigation have been recorded in literature [7, 8, 9, 10, 11, 12]. The field data acquisitions were carried out on some selected farmlands in part of Krakow, Poland where natural in-situ settings of the horizons have not been distorted.

## Purpose and scope of work

The research study was aimed at utilizing integrated remote sensing and geophysical datasets to assess the physical properties of the soil particularly to circumvent the pitfalls of the traditional approaches hitherto used. It is worth noting that the test sites were arbitrarily selected for the applicability of the chosen techniques and thus, the results are not the general representation of the soil properties of the area of measurement.

## Material and methods

Modeling of the subsurface horizons and the simulation of the corresponding response of the electromagnetic pulse energy that propagated through them was the first stage of the research study. This modeling concerns the GPR method being the major test method. This was carried out to ascertain the possibility of evaluating the sought parameters and also verify the effects of attenuation that may hinder the depth of penetration. It was performed using gprMax- an open-source software developed by [13,14]. Figure 1 shows models computed using the soil mixing ratio theory postulated by [15] and the corresponding GPR A-scans generated using gprMax software. Sequel to the model results, substantial information such as possible input parameters and antenna frequency that may be used for field measurements was obtained. The actual field measurements were carried out using both the constant offset and wide-angle reflection and refraction techniques for the GPR method. Details of the GPR techniques are found in the literature [16,17,18, 19]. The other integrated methods (EMC and hyperspectral imaging) measurements were performed at selected points at the test sites. The field layout and the survey traverses on which data were acquired at some of the test sites are shown in Figure 2. Soil compactness was simulated using various passes of a tractor with an average weight of 3500 kilograms (fig 2b). Some soil samples to perform traditional soil assessment were also taken. This was with a view of correlating with the results of the geophysical datasets.

Field data processing was carried out using reflexW developed by Sandmeier incorporation [20] and opendTect developed by dGB earth science [21], with their associated accessories. Before the data processing there was the qualitative examination, and corrections through editing to ensure a reduction in noise and guarantee high-quality data. Subsequently, the data were processed where they were subjected to filtering stages, particularly to remove recalcitrant noise and clutters thus enhancing the signal-to-noise ratio of the data.

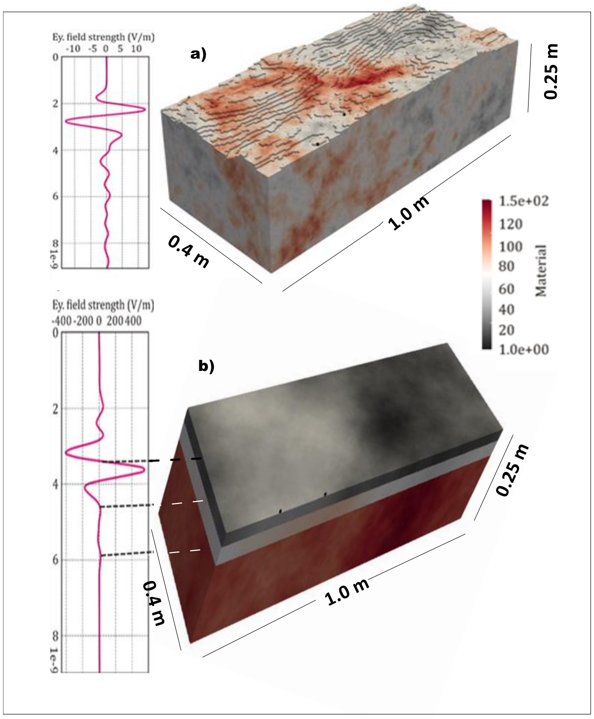

Fig.1. 3D modeling of soil layers to GPR response (a) One layer (with mixed components) model (b) Three layers (with mixed components) model. With corresponding GPR A scan

Furthermore, mathematical manipulation of the processed data also facilitated its enhancement and thus according to [22], allowed the delineation of subtle features of the data that were concealed even after the filtering stages. Field-recorded GPR signal attributes such as the instantaneous phase, and spectral decompositions were computed to enhance appropriate interpretation of the field data. The inverse modeling technique was used to analyze the EMC data while the hyperspectral image data were presented and processed in MATLAB [23] where the spectral reflectance variation with respect to the spectrum wavelength was displayed. Evaluated parameters from the field data were used as input in some petrophysical empirical relationships (equations 1 and 2) [24,25]. Equations 1 and 2- complex refractive index model(CRIM) [25] were used for the calculation of state variables such as volumetric water contents and porosity, while other actual physical property such as bulk density was evaluated from these parameters.

$$\theta = -5.3 \cdot 10^{2} + 2.92 \cdot 10^{-2}\,\varepsilon_r - 5.5 \cdot 10^{-4}\,\varepsilon_r^{2} + 4.3 \cdot 10^{-6}\,\varepsilon_r^{3} \tag{1}$$

where: θ is the water contents, $\varepsilon_r$ is the relative permittivity.[8]

$$\varepsilon_{rc}^{\alpha} = \theta\varepsilon_{rw}^{\alpha} + (1-\eta)\varepsilon_{rs}^{\alpha} + (\eta-\theta)\varepsilon_{ra}^{\alpha} \tag{2}$$

where $\varepsilon_{rc}$, is the relative permittivity of the composite material. $\varepsilon_{rs}$, $\varepsilon_{rw}$, $\varepsilon_{ra}$, are the relative permittivity of the solid, aqueous, and gaseous phase respectively. η is the porosity while θ, 1-η, η-θ are volume fractions of the constituents [9].

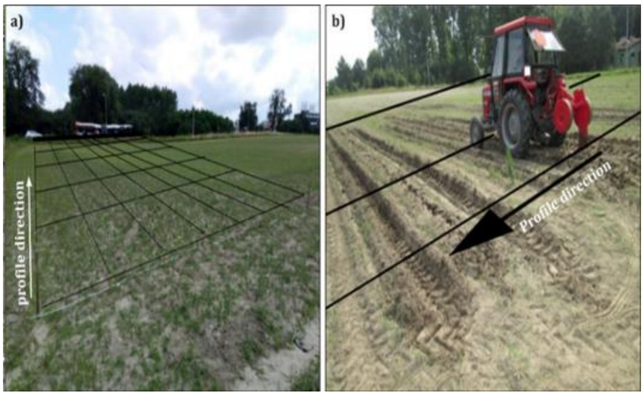

Fig.2. Field data acquisition layout

## Results

Analysis of the GPR processed field data enabled the delineation of the subsurface horizons at the test sites which was the first lead to further probe to understanding the physical properties. Figure 3 (a and b) shows the processed and transformed GPR data revealing the soil horizons. The vertical variability of the subsoil is easily discernible which was interpreted as the soil layers In Figure 4 are the displayed results of the identified compacted zones from the GPR data. The technique allows the evaluation of the spatial variations in the compactness at the test sites and the reaction of the propagated EM pulse energy within the compacted zones.

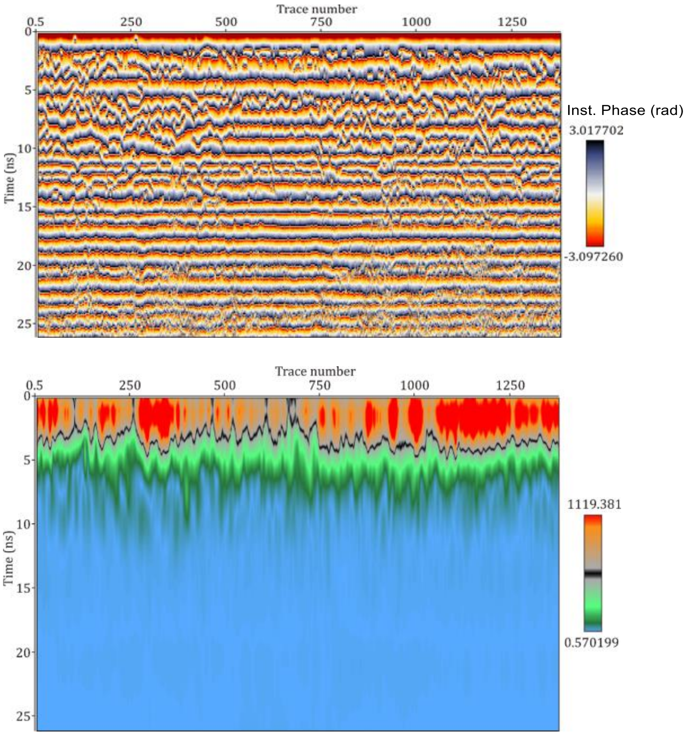

Fig.3. Field data analysis and results: GPR data attributes depicting soil horizons. a.) 2D GPR Instantaneous phase attribute b.) Spectral decomposition of 2D GPR section

In particular, Figure 4 displays the image of the compacted and non-compacted soil zones by the tractor. Alteration of the topmost horizon of the soil can be seen portraying a seemingly constant thickness (area marked with cyan dotted line fig. 4a) identifying the zone of compaction. The probable explanation is that the vertical exerted impact of the tractor movement may have been evenly distributed causing the appearance of the seemingly constant thickness. However, irregular reflection continuity appears on the same horizon with visibly distinguishable hyperbolas (dotted cyan eclipse. Fig. 4b) on a section with no tractor passes.

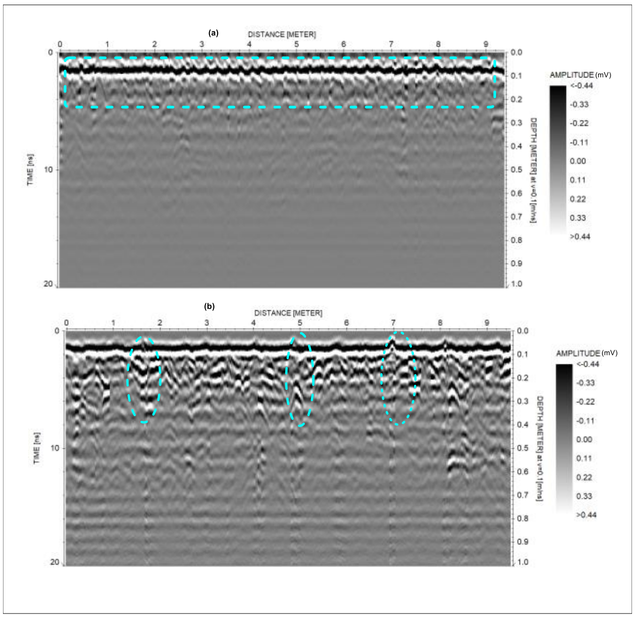

Fig.4. Soil compactness delineation from the GPR data plot. a) Profile along traffic (b) Profile parallel to (a) without traffic.

The correlation of the evaluated volumetric water content of the soil with the gravimetric technique is shown in Figure 5. The positive correlation portrayed the similarity in the techniques.

Similarly, the results of the integrated techniques were compared as shown in Figure 6. The EMC and GPR evaluated results indicated a good correlation. Hyperspectral Imaging data analyses at some selected points within the test site were also in agreement with the other techniques deployed for the study. In Figure 7, the reflectance curves at different points of sampling indicated a decrease in the soil moisture content with depth where a similar trend was recorded from the EMC data at the same point.

## Conclusion

Attempts have been made in this research study to test the feasibility of adopting geophysical and remote sensing techniques for soil physical properties assessment to circumvent the gaps in the traditional soil survey methods. The soil horizons are easily delineated using the techniques. Analysis of the pulse signals from the processed field data served as inputs to estimating the soil's state properties such as volumetric water content as well as other physical attributes such as bulk density and porosity. Findings from the experimental tests have shown a relatively positive correlation of the approaches' outcomes with the control test using conventional methods. The swiftness of the adopted techniques coupled with the likelihood of continuous measurement which may bridge the gaps of interpolation of results of traditional methods and at the same time enhance repeated field evaluations showed that they can be utilized in soil surveys.

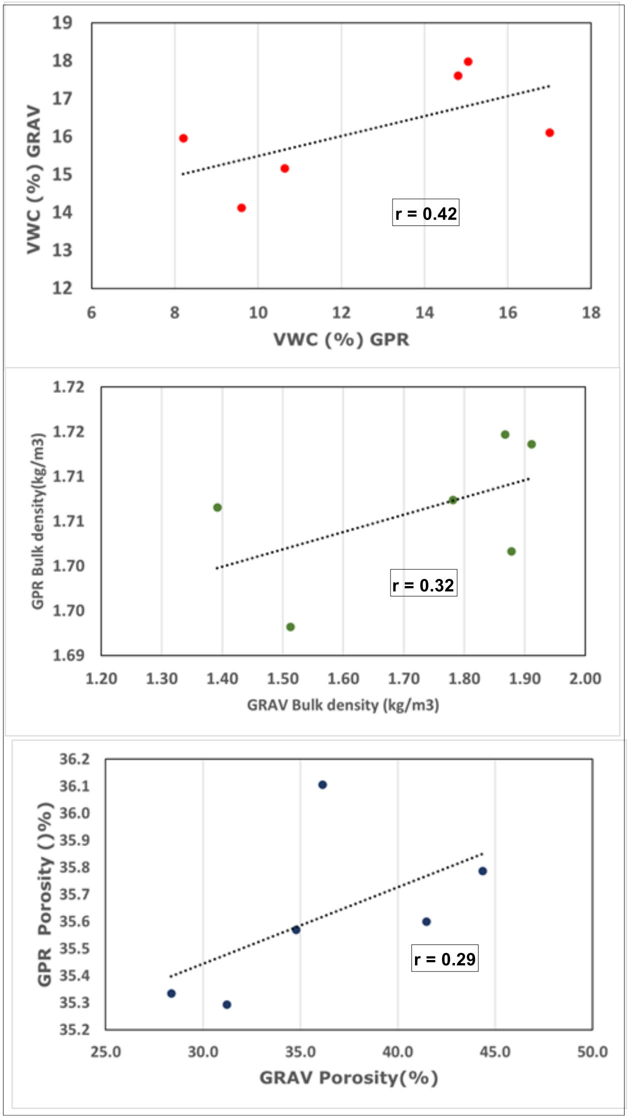

Fig.5. scatter plot of estimated volumetric water content by GPR and gravimetric methods.

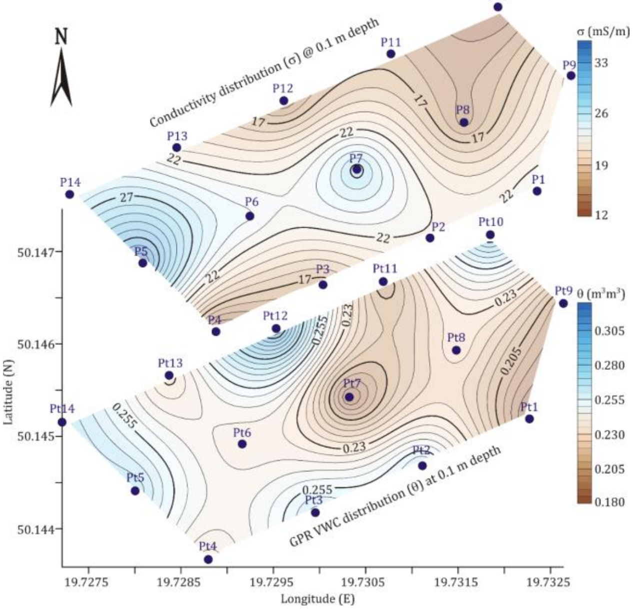

Fig.6. Field data analysis and results: a) spatial comparison of the GPR and EMC results

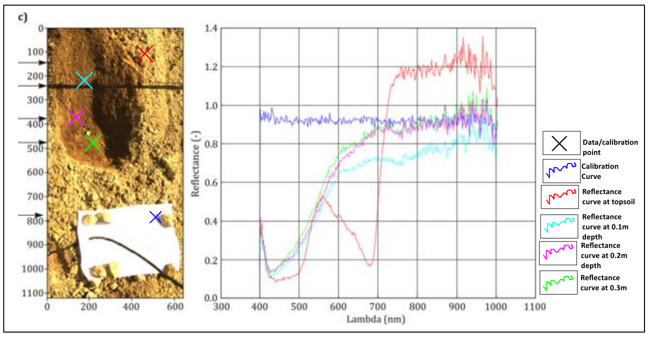

Fig.7. Hyperspectral imaging reflectance plot of a selected point at a test site.

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