Methods for prediction of soil dielectric properties: a review

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ABSTRACT

Electromagnetic sensors such as ground penetrating radar and electromagnetic induction sensors are among the most widely used methods for the detection of buried landmines and unexploded ordnance. However, the performance of these sensors depends on the dielectric properties of the soil, which in turn are related to soil properties such as texture, bulk density, and water content. To predict the performance of electromagnetic sensors it is common to estimate the soil dielectric properties using models. However, the wide variety of available models, each with its own characteristics, makes it difficult to select the appropriate one for each occasion. In this paper we present an overview of the available methods, ranging from phenomenological Cole-Cole and Debye models to volume-based dielectric mixing models, and (semi-) empirical pedotransfer functions.

Keywords: dielectric soil properties, phenomenological models, mixture models, (semi-)empirical models

1. INTRODUCTION

Buried land mines and unexploded ordnance (UXO) are present in a large number of countries around the world. They can be found at the locations of past military conflicts or at active and abandoned military training sites. The presence of land mines and UXO cause serious safety hazards, which require the clean up of contaminated land. Many of the geophysical methods for detection of buried landmines and UXO make use of electromagnetic signals. Dielectric medium properties are a critical parameter for most methods, because the dielectrics control the contrast between the object of study and the medium it is buried in. Additionally the dielectric medium properties control propagation, attenuation, and reflection of electromagnetic waves. The dielectric properties of a material are a function of among others: texture, bulk density, mineralogy, organic matter content, and frequency, but especially water content\textsuperscript{1}.

Previous work has shown the effect of spatial and temporal variability in the soil system. A significant part of the variability in landmine and UXO signatures can in fact be attributed to the temporal and spatial variability that is present in soils. Soil data from a wide range of environmental settings (temperate, tropical, and desert) show that soil water content varies widely and over distances of less than one meter\textsuperscript{2-4}. This variability has important implications for sensors that are affected by the soil water content, as their performance may be variable over short distances. The performance of a sensor under specific soil conditions can be predicted using a thorough understanding of the physics of the soil-mine-sensor system.

To predict the performance of electromagnetic sensors it is common to use models that estimate the soil dielectric properties. Although a wide variety of models, each with its own characteristics, has been proposed no complete model is available that can describe the dielectric properties of a soil for all its variables\textsuperscript{5,6}. This makes it a challenge to select the best model for each occasion. The available methods can be grouped in (1) phenomenological (e.g., Cole-Cole and Debye), (2) volumetric, (3) empirical and semi-empirical (pedotransfer), and (4) effective medium models or approaches. The effective medium approach, or composite spheres model\textsuperscript{7-10}, is only accurate for known geometries and difficult to implement for heterogeneous and multiple-phase materials\textsuperscript{11,12}. We consider this approach irrelevant for the problems of UXO and landmine detection and it will be ignored in this paper.

We present a literature review of the available methods for prediction of dielectric properties of field soils. This review is an attempt to introduce the major groups of approaches. We discuss the most important exponents and publications of