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Research paper

Investigations on magnetic characteristics of the soil and their influence on its dielectric response

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ABSTRACT

Conventionally, soils have been characterized based on their physical, chemical and mineralogical characteristics. However, in order to address various geo-environmental issues that have become a threat for the modern day civilization, soils have also been characterized based on their electrical properties. Furthermore, it has been demonstrated that the electrical properties of the soil mass (i.e., the soil compacted at a certain dry density and water content) are instrumental, primarily, in measuring its volumetric moisture content. In this context, though several efforts have been made by earlier researchers to determine dielectric response of the soil mass, the effect of soil magnetic characteristics on dielectric response and volumetric moisture content has not been established yet. Hence, development of a methodology to determine magnetic characteristics and their relationship with the dielectric response of the soil mass, if any, becomes quite intriguing. With this in view, soils of entirely different characteristics were tested for their magnetic characteristics (viz., remnant magnetization, coercivity and magnetic hysteresis area) by employing a magnetometer. Furthermore, these characteristics have been correlated with the physical, chemical, mineralogical and electrical properties (dielectric dispersion obtained from an impedance analyzer) of the soil. The study demonstrates that the parameter "area of magnetic hysteresis" of the air dried soils has significant influence on soil specific parameters such as specific gravity, iron content and dielectric constant. This preliminary study also proposes a hypothesis to obtain volumetric moisture content of the soil mass based on its magnetic characteristics and dielectric constant, which can be obtained from an impedance analyzer. However, efficiency and utility of the proposed hypothesis should be demonstrated by testing a large number of soils from different parts of the world.

1. Introduction

Soil characterization is the basic step for understanding its properties that are essential for studies related to agriculture, civil, geotechnical and environmental engineering. Soils are generally characterized based on their physico-chemico-mineralogical properties by resorting to well established protocols (ASTM D 4318-10, 2013; ASTM D 5550-06, 2006; ASTM D 422-63, 2007; ASTM D 427-93, 1999; Kolay and Singh, 2001). Moreover, it is a well-known fact that for obtaining these soil specific parameters, one has to resort to time consuming and elaborate testing protocols (Sur and Kukal, 1992; Nettleship et al., 1997; Bartake and Singh, 2005; Shanthakumar et al., 2010; Kadali et al., 2016), which are mainly laboratory based but invasive and destructive in nature. However, due to the severity associated with the geoenvironmental issues (viz., ground water contamination, subsurface water profiling, monitoring of leachate in the landfill, soil salinity, oil spill, slope instability and landslide), in-situ measurements and monitoring of soil-specific parameters have become important in the present day context. In order to address these issues, researchers (McCarter, 1984; Abu-Hassanein et al., 1996; McCarter and Desmazes, 1997; Rohini and Singh, 2004; Shah and Singh, 2004) have established soil characterization based on electrical properties (viz., conductivity and dielectric response) of the soil mass (viz., matrix of the soil resulted from its compaction corresponding to a certain dry density and moisture content), which facilitates in-situ, instantaneous and non-invasive measurements of the soil-specific parameters. Incidentally, dielectric constant (Topp et al., 1980; Bhat et al., 2007; Susha Lekshmi et al., 2014), electrical conductivity (Shah and Singh, 2004; Bai et al., 2013) and dielectric dispersion (Thevanayagam, 1993; Rinaldi and Francisca, 1999; Bhat et al., 2007) of the soil mass have been employed for determining its volumetric moisture content (Topp et al., 1980; Susha Lekshmi et al., 2014), degree of saturation (Abu-Hassanein et al., 1996), degree of compaction (McCarter, 1984), porosity, permeabilityand fabric structure (Mitchell and Arulanandan, 1968; Gumaste and

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Nomenclature

θ	volumetric moisture content
γ_t	soil bulk unit weight
γ_d	dry unit weight of soil
n	porosity
emu/g	electro-magnetic unit per gram
Oe	Oersted
S_r	saturation
w	gravimetric moisture content
AH	area of hysteresis curve bound between $\pm CR$ and $\pm RM$
CT	Capacitance Technique
CR	coercivity
G	specific gravity
H	magnetic field
K_a	dielectric constant
$K_{a\text{-Expt.}}$	dielectric constant of the soil mass obtained by employing an impedance analyzer
$K_{a\text{-mineral}}$	dielectric constant of the soil in its dry and powder states
M	magnetic moment
RM	Remnant Magnetization
T	Tesla
TDR	Time Domain Reflectometry
TP	Time Propagation

Singh, 2010).

Geophysical techniques, which are mainly electromagnetic based (most of the state-of-the-art techniques viz., Time Domain Reflectometry, TDR, Frequency Domain Reflectometry, FDR, and the capacitance) employ dielectric response of the soil mass to measure its in-situ moisture content (Susha Lekshmi et al., 2014). As dielectric response of the soil mass depends on its matrix (mainly the pore-solution, mineralogical constituents of the soil and their dielectric constant, density and porosity), earlier researchers have proposed various relationships linking dielectric constant of the soil mass, its moisture content (Topp et al., 1980, 1982; Susha Lekshmi et al., 2017), mineralogical composition and dielectric constant of these minerals by employing Time Propagation (TP) mixing model (Dobson et al., 1985; Martinez and Byrnes, 2001). However, quantification of the soil minerals and their dielectric constant is an arduous task as it warrants employment of X-ray powder diffractometer (XRD) and X'Pert High Score Plus software with PDF-4+ database, which are expensive and expertise oriented. Incidentally, the above mentioned studies do not consider the effect of magnetic characteristics of the soils, which are mainly related to the velocity of the electromagnetic waves in the soil mass, on their dielectric response (Mohamed, 2006). This also gets substantiated by the fact that magnetic characteristics of the soil would be of utmost importance for estimating the travel time and the propagation velocity of electromagnetic waves in the soil mass (Mohamed,

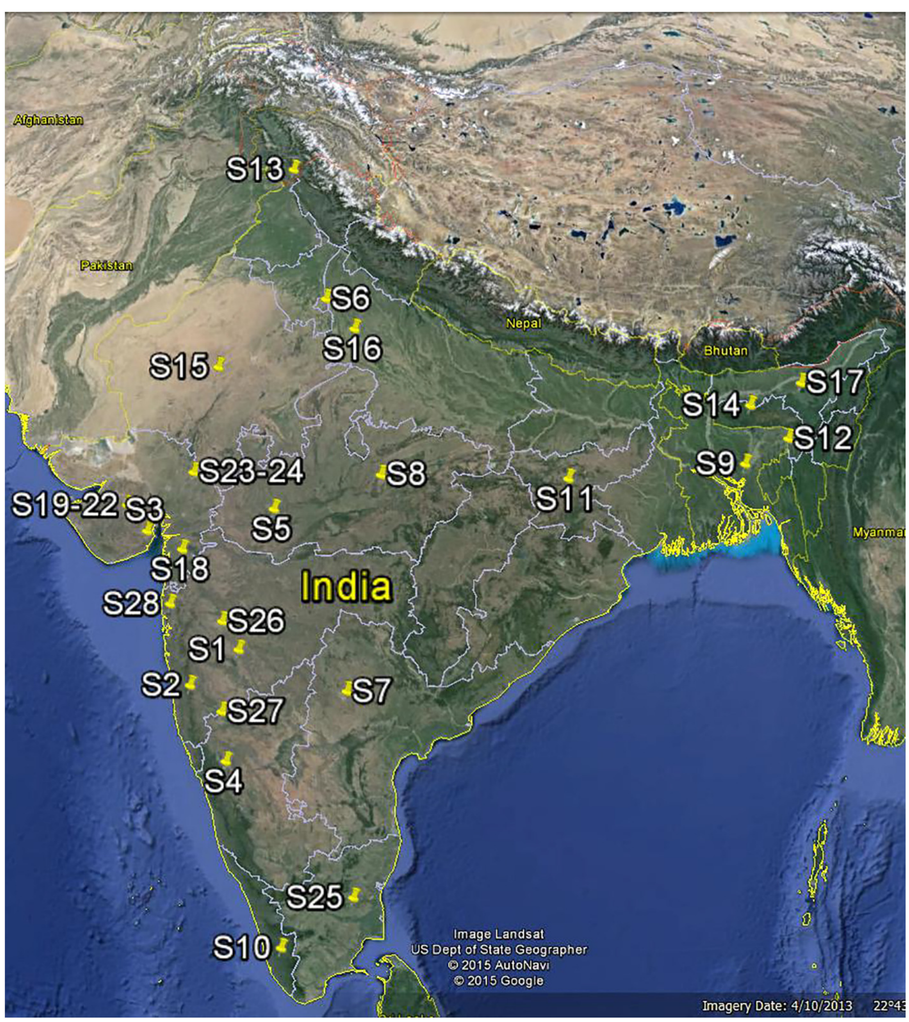

Fig. 1. Location of the soil samples collected forthe study.