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Review

A critical review of soil moisture measurement

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ABSTRACT

Soil moisture content has paramount importance in dictating engineering, agronomic, geological, ecological, biological and hydrological characteristics of the soil mass. Though earlier researchers have employed various techniques of moisture content determination of soils, both in laboratory and in situ conditions, ascertaining the applicability of these techniques to soils of entirely different characteristics and the 'types of moisture content', which they can measure, is still a point of debate. As such, a critical review of all the established and emerging soil moisture measurement techniques with respect to their merits and demerits becomes necessary. With this in view, efforts have been made in this paper to critically evaluate all the soil moisture measurement techniques, limitations associated with them and the influence of various soil-specific parameters (viz., mineralogy, salinity, porosity, ambient temperature, presence of the organic matter and matrix structure of the soil) on the measured soil moisture content. This paper also highlights the importance of various innovations based on Micro Electro Mechanical Systems (MEMS) and nano-sensors that are emerging in this context.

Contents

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Nomenclature

θ	volumetric moisture content	ε_0	free space permittivity
w	gravimetric moisture content	ΔT_m	the maximum raise in temperature
γ_τ	soil bulk unit weight	f	frequency
γ_d	dry unit weight of soil	L	length
γ_w	unit weight of water	M	mega
η	porosity	M_1 M_2	percentage of minerals present in the material
σ_{dc}	conductivity corresponding to zero frequency	m	meter
°C	degree Celsius	mA	milliampere
atm	atmospheric pressure	mm	millimeter
g	gram	n	nano
eV	electron-volt	Hz	hertz
dS/m	deci Siemen per meter	q	energy applied per unit length
k	dielectric constant	Sr	saturation
k_a	apparent dielectric constant	ERI	electrical resistivity imaging
k_{M_1} k_{M_2}	dielectric constant of minerals	DPHP	dual probe heat pulse
K^*	complex dielectric constant	FDR	frequency domain reflectometry
K'	real dielectric constant	GPR	ground penetrating radar
K''	imaginary dielectric constant	MEMS	micro electro mechanical systems
kPa	kilopascal	NMM	neutron moisture meter
t	time	SWCC	soil water characteristic curve
ω	angular frequency	TDR	time domain reflectometry

1. Introduction

Soil moisture (water) is an inevitable part of the three-phase system of the soil, which comprises of soil minerals (solids), moisture and air [1,2]. Hence, soil moisture content has quite significant influence on engineering [3], agronomic [4,5], geological, ecological, biological and hydrological behavior [6–8] of the soil mass. Mechanical properties of the soil viz., consistency, compatibility, cracking, swelling, shrinkage and density are dependent on the soil moisture content [3,9]. Furthermore, it has a major role to play as far as the plant growth [5], organization of the natural ecosystems and biodiversity [10] is concerned. In agriculture sector, application of adequate and timely moisture for irrigation, depending upon the soil-moisture-plant environment, is essential in crop production [11–14]. Space–time evolution of the soil moisture content is controlled by topography, landscape position, slope, vegetation, soil structure and texture and human-made structure above the soil. Moreover, according to the environmental conditions, soil state can be varied from the dry to saturated state [3,6,7,9,10]. Considering the aforementioned facts, determination of the amount of moisture in the soil (i.e., the soil moisture content) becomes quite crucial in the field of agricultural, geotechnical, hydrological and environmental engineering. Soil moisture content is also used as an important parameter for water balance studies, slope stability analysis and performance evaluation of various geotechnical structures such as pavements, foundations, earthen dams, retaining walls, compacted clay liners, hazardous and toxic waste disposal repositories and wherein contaminant transport within the vadose zone is of utmost importance. [1–3,6,10,15]. In short, physical, chemical, mineralogical, mechanical, geotechnical, hydrological and biological properties of the soils are heavily dependent on the soil moisture content.

In this context, earlier researchers have developed several techniques for measuring the soil moisture viz., thermo gravimetric [10,16–19], neutron scattering [20–25], soil resistivity [26,27], dielectric techniques like time domain reflectometry, frequency domain reflectometry and capacitance etc. [28–47]. However, these techniques are quite intricate, expensive (due to quite elaborate circuitry and paraphernalia) and hence beyond the reach of many. Also, ascertaining the applicability of these techniques to soils of entirely different characteristics and the 'types of moisture', which they can measure