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Estimation of Soil Moisture Content: A Review

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Abstract

Soil moisture content is most important nutrient present in the soil. Usually, soil moisture is affected by soil physical properties such as soil color, texture, structure and bulk density. It is significant parameter for several applications in hydrology, horticulture, agriculture and meteorology. It influences plant growth, percolation, evaporation and heat exchange. Different measurement techniques were adopted to estimate soil moisture content ranging from classical to modern approaches which may or may not be influenced by soil physical properties. Currently, hyperspectral remote sensing is largely contributing in soil moisture content measurement and producing improved results over traditional methods. In this context, this paper focuses on evaluation of existing soil moisture content estimation techniques and some derived approaches by researchers.

Keywords: Soil moisture content, measurement techniques, spectral reflectance

I. INTRODUCTION

Soil moisture content plays a key role in the crop production as it act as a nutrient and serves as solvent for other nutrients such as sodium, potassium, carbon, nitrogen. It makes a significant impact on plant growth, percolation, evaporation, microbiological decomposition of the soil organic matter and also on heat exchange. The moisture content in the surface layers of the soil is an important parameter for many applications in hydrology, horticulture, geotechnical, agriculture and meteorology.

In agriculture point of view, soil moisture information is essential for many applications like irrigation scheduling, plant stress and improving crop yield. Soil moisture also determines the partitioning of net radiation into latent and sensible heat components in the field of meteorology. Therefore, accurate soil moisture estimates are essential in several applications as to examine the effect of climate change on land surface hydrological variables such as soil moisture, infiltration fluxes, runoff and surface temperature caused by changes in heat fluxes and to quantify the amount and variability of regional water resources in water limited regions of the world on seasonal.

In recent decades, different methods are available to estimate soil moisture content which can be categorized into classical and modern techniques for both the laboratory and in situ measurements. Classical soil moisture measurement involves removing moisture from the soil sample by evaporation or chemical reaction comprises of thermo-gravimetric and calcium carbide techniques. Modern soil moisture measurement techniques employ electrical properties of the soil (viz., dielectric constant, impedance, capacitance and soil resistivity), neutron scattering, gamma attenuation and optical techniques. Now, emerging technique is remote sensing technique in which soil moisture estimation depends upon the measurements of electromagnetic energy that has either been reflected or emitted from the soil surface.

In this paper, we have evaluated different measurement techniques most widely used to estimate soil moisture content and some proposed techniques by researchers.

II. RELATED WORK

Angström A. concluded from laboratory experiments that soil spectral reflectance shows traces of soil moisture content. Results showed that darkening of soil surface causes increase in soil moisture content and hence decreases the reflectance level of soil. [1]

In 1987, American Society for Testing and Materials (ASTM) published standard test method which uses microwave oven for estimating soil moisture content. It stated that it is alternative to conventional oven. [2]

Bach, H.; Mauser, W., confirmed_the behavior proposed by Angstrom and then spectral reflectance is used to develop soil moisture content approaches. [3]

E.E.Abdel-hady, A..M.A..EL-Sayed and H.B.AIaa* used X-ray spectroscopy system for soil moisture content (SMC) estimation which includes two combined sources (^{137}Cs & ^{241}Am) & 5 x 5 cm NaI(TI) scintillation detector. This method allows estimation of bulk density and soil moisture content simultaneously. It is concluded that the bulk density at dry and wet stages remain unaffected as there is no rearrangement during wetting and drying process. [4]

Authors *K. Grote, S. Hubbard , Y. Rubin* used Ground Penetrating Radar (GPR) to measure soil moisture content using 450 & 900 MHz antennas. It is observed that multi-frequency GPR should be used to calculate soil moisture content at different depths. The results can be used to identify soil texture. [5]

Michael L. Whiting, Lin Li, Susan L. Ustin presented an approach fitting an inverted Gaussian function to estimate moisture content. This approach includes declining reflection in NIR and SWIR regions as there is water absorption at 2.8Am. Convex hull boundary points and inverted Gaussian functions are fitted. It is concluded that both area and amplitude of inverted Gaussian has high relationship. [6]

J.A.M. Demattê , Antonio A. Sousa Marcelo C. Alves , Marcos R. Nanni ,Peterson R. Fiorio, Rogério Costa Campos stated that reduction in the magnitude of spectral reflectance of samples represents increase in soil moisture between 450 & 2500nm. 1400 & 1900nm stared to show narrower impression as soil loose moisture. [7]

Willem W. Verstraeten 1,, Frank Veroustraete 2 and Jan Feyen* provided extract of soil estimation technique at different temporal and spatial scales. Different spatial scales (field water balance, sap-flow, Bowen ratio, scintillometer, porometer, lysimeter, eddy correlation) for evapotranspiration (ET) and SMC assessment was considered. It is concluded that scale is primary issue in hydrology. [8]

Haubrock, S.; Chabrillat, S.; Lemmnitz, C.; Kaufmann, H. proposed new approach called Normalized Soil Moisture Index (NSMI) in spectral range (350-2500nm). In this study, natural soil samples were observed under all wavelengths and combinations of bands were found with relationship to soil moisture. From the results, it is concluded that NSMI remains unchanged under effect of surface crusts or substrate heterogeneity. [9]

Soren-Nils Haubrock¨, Sabine Chabrillat, Matthias Kuhnert, Patrick Hostert and Hermann Kaufmann studied NSMI to Hyperspectral data. Surface soil moisture map is built by combining Frequency Domain Reflectometry (FDR) and gravimetric data. They have concluded that NSMI is best suitable to estimate SMC from high spectral resolution remote sensing data. [10]

The research done by *Michael L. Whiting* specifies that the loss of mineral band depth is observed above SWIR. This relation is non-linear. This can be used for estimation of mineral. Absorption bands can be used as index and as predictors of soil biological crust, such as cyanobacteria, in hyperarid soils. [11]

Heyam Daod studied microwave radiation against convection to determine accuracy & soil drying duration. Results show that convection oven produces true values for both soil liquid limit & natural moisture content. [12]

Marion Pause, Karsten Schulz, Steffen Zacharias, and Angela Lauschd concluded in their study that data obtained from inversion of airborne & satellite L-band radiometer provides estimation of soil moisture. In this study, the evaluated effect of LAI against airborne L-band brightness temperature of crop canopies. [13]

The objective of research of *Jian Peng, Hong Shen, San Wei He, Jian Sheng Wu* was to evaluate Discrete Wavelet Transform (DWT) to find SMC. DWT was used to decompose the hyperspectral data into a large subset of corresponding wavelet coefficients. Then, they were calculated into energy coefficients at each corresponding decomposition levels. By using DWT, we got sensitive soil moisture information of original signals with reduced dimensionality.

[14]

The study of *Chikkappa Udagani* aimed to find moisture content from the clay brick using Gamma radiation with the help of Gspec gamma ray spectroscopy system & Sc^{137}. The values of % of fractional change in linear attenuation coefficient are found to be very close to the values of moisture content of the clay brick. [15]

Parinaz Rahimzadeh-Bajgiran[a,*], *Aaron A. Berg*[a], *Catherine Champagne*[b], *Kenji Omasa*[c] proposed new approach based on evaporative fraction (EF) using optical/thermal infrared MODIS data. Basic concept is to obtain value of EF i.e. remotely sensed land surface temperature(Ts) / vegetation index by incorporating North American Regional Reanalysis (NAAR) Ta data for soil moisture estimation. [16]

Alpana Shukla, Harsh Panchal*, Mayank Mishra+, P. R. Patel+, H.S. Srivastava^, Parul Patel*[#]*, A.K.Shukla*[#] provided comparison of FDR moisture value & soil sample moisture values. The results showed that there is high correlation between moisture value of FDR & soil sample. Thus, FDR moisture value can be used to estimate SMC. [17]

Susha Lekshmi S.U. , D.N. Singh , Maryam Shojaei Baghini concluded summary of different SMC estimation methods like classical techniques viz., thermogravimetric and calcium carbide test and modern techniques viz., neutron scattering, gamma attenuation , dielectric techniques including TDR, FDR, GPR, tensiometer and optical techniques. [18]

Attila Nagy, Péter Riczu, Bernadett Gálya, János Tamás used spectral reflectance of soil samples to estimate SMC. The reflectance curve of sand & sandy loam soil is linear with the wavelength & gradual increase of clay soil sample curves. [19]

Sophie Fabre, Xavier Briottet and Audrey Lesaignoux recorded spectral signatures of the collected soil samples in the reflective domain (0.4-2.5 μm). Then they compared performance of new approaches to calculate SMC against available SMC estimation indices like NSMI and Water Index SOIL (WISOIL). [20]

III. METHODOLOGY

*E.E.Abdel-hady** used a single collimator, ^{241}Am and ^{137}Cs radioactive sources emitting 60 and 662 keV gamma-ray were placed. Inside plastic column (5x5x10 cm^3), samples were packed.

In the work of *Jian Peng*, hyperspectral data were decomposed using DWT into a large subset of corresponding wavelet coefficients. In this study, 13 different mother wavelets along with six decomposition levels from 5-10 are identified for selected data.

Attila Nagy observed soil samples on the 1000-2450 nm spectral range by AvaSpec 2048. Spectral signatures of data were grouped and calculated the standard deviation curves: 0-5%, 5-10%, 10-15% etc. (percentage of dry weight). Differences in reflectance between the soils were examined through Tukey's multiple-factor analysis of variance.

IV. RESULTS AND DISCUSSION

*E.E.Abdel-hady** concluded that the bulk density at dry and wet stages remain unaffected as there is no rearrangement during wetting and drying process. This method allows estimation of bulk density and soil moisture content simultaneously.

In the work of *Jian Peng* , the performance evaluation between band selection & DWT were compared using three indices i.e. R^2, R_{adj} and root mean square error (RSME). It is concluded that DWT reduced the hyperspectral dimensionality, thus giving better results. Among the 78 estimation models , there were 42 models superior to band selection, with 24 models yielding good correlations between the predicted soil moisture and the measured ones ($R^2 >= 0.7$, RMSE <= 0.050, p <= 0.05).

Attila Nagy results shows that reflectance was low (8-14%) at the 400-420 nm range regardless of soil texture. Reflectance was increased from 480nm and touched the peak at 980-1000nm in NIR range.

V. CONCLUSION

A synthesis of the reviewed literature indicates that most widely used method is gravimetric method due to its accurate results. But, it is somehow destructive SMC measurement technique. Other methods such as dielectric techniques i.e. TDR, neutron scattering, ground penetrating radar and optical techniques. But, these methods are expensive. Currently, hyperspectral remote sensing techniques are widely used due to availability of high resolution satellites and its large coverage area. Researchers have found relationship between spectral reflectance characteristic of soil and soil moisture content in NIR and SWIR range of solar domain.

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