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# ESTIMATION OF SOIL MOISTURE BY REMOTE SENSING AND FIELD METHODS: A REVIEW

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## Abstract

Understanding the spatial and temporal variations of soil moisture is crucial for the land surface processes and their management. Accurate estimation of spatial and temporal variations of soil moisture is important for various hydrological studies also. Recently, remote sensing techniques have been used to estimate soil moisture. Estimation of soil moisture by remote sensing techniques provides only surface layer information and is unable to observe the entire soil column. On the other hand field measurement provide valuable information regarding both surface and subsurface soil moisture, but are insufficient to characterize the spatial and temporal variability of soil moisture at larger scale. Therefore, remote sensing methods have an edge over field methods in terms of spatial and temporal scale. Soil moisture variations in time and space are controlled by many factors, such as soil texture, vegetation, topography and groundwater table depth. Groundwater table depth, play an important role in determine of soil moisture. It acts as a source of soil water having substantial effect on soil moisture in areas, where water table is within soil column. This paper presents a comprehensive review of the progress in remote sensing as well as field methods for soil moisture studies.

**Key words**: Soil moisture estimation, remote sensing, f methods, Groundwater table

## Introduction

Soil moisture can be defined as the water in the unsaturated part of the soil profile, i.e. between the soil surface and the ground water level [32]. Soil moisture status is essential for climate change studies, and for conducting soil water balances. Soil moisture data is necessary for parameterizing numerical models, which are used to estimate evapo-transpiration from land cover, and deep percolation for groundwater impact studies. Spatial and temporal variability in soil moisture results by variations in soil texture, topography, crop cover, irrigation practices and groundwater level depth [26]. Estimation of the soil moisture is important for water resource management, for meteorological and agricultural applications [64].

Soil moisture in the upper part of the earth's surface has been recognized as a key variable in numerous environmental studies, including meteorology, hydrology, agriculture and climate change [5], [19], [21], [22], [34], [56], [59]. Therefore, it is important to monitor and estimate accuracy the spatial and temporal variations of soil moisture.

Nowadays direct observations of soil moisture are restricted to discrete measurements at specific locations and such point-based measurements do not represent the spatial distribution, because soil moisture is highly variable both spatially and temporally [18], [71]. Development in remote sensing satellite technology has offered a number of techniques for estimating soil moisture across a wide area continuously over time [17]. In mid 1970's, research on soil moisture remote sensing began shortly after the rapid development in satellite techniques. Subsequent research effort is needed for many diverse paths, spanning most of the electromagnetic spectrum from optical to microwave region [42]. Many researchers have shown that surface soil moisture content can be measured by optical and thermal infrared remote sensing, as well as passive and active microwave remote sensing techniques [48]. The primary difference among these techniques are the wavelength region of the electromagnetic spectrum used, the source of the electromagnetic energy[65] the response measured by the sensor and the physical relationship between the response and the soil moisture content[50].

Soil moisture content can't be measured directly by remote sensors; mathematical models are derived to determine the connection between the measured signal and soil moisture content [15]. Recently, technological advancement in remote sensing has shown that soil moisture can be estimated by a variety of remote sensing techniques on large scale [11] each has its own advantage and weaknesses [30]. Techniques in the optical/IR and microwave regimes have attracted more attention [10]. Optical/IR techniques can provide fine spatial resolution for soil moisture estimation. Microwave technology has demonstrated a quantitative ability to estimate soil moisture physically for most ranges of vegetation cover [46]. However, the channel frequencies and the spatial resolution of current satellite microwave radiometers are not optimal for land remote sensing due to practical problems in supporting a large, low frequency antenna in space [74]. Some attempts have been made by combining the strengths of microwave as well as optical/IR remote sensing approaches for soil moisture estimation. In this paper we present a comprehensive review of the commonly used field methods and remote sensing technique for soil moisture estimation, including their physical principles, advantages and weaknesses.

# Remote sensing and soil moisture

### Historical background

From last few years remote sensing techniques has been introduced to estimate soil moisture content over land surface. Remote sensing techniques give large scale spatially distributed and frequent coverage of a phenomenon [33], but soil moisture estimation from the remote sensing techniques only provides surface layer information and is unable to observe the entire soil column. On the other hand the in-situ measurements provide valuable distributed point measurements, but are insufficient to characterize the spatial and temporal variability of soil moisture at larger scale. Therefore observations that are made by remote sensing techniques have an edge over the conventional data collection methods in terms of the spatial and temporal scale.

Remote sensing based soil moisture content measurements using the solar domain with wavelengths between 0.4 and 2.5 μm measures the reflected radiation of the sun from the earth's surface, known as reflectance [ 55]. As compared with microwave and thermal infrared domains that have been most commonly used for soil moisture estimation [51], [72], [20], [35], little attention has been paid to the use of the solar domain [41]. However, many investigations have shown that the solar domain also provides the capability for soil moisture estimation. Early in 1925, effect of soil moisture on its reflectance has long been recognized by many scientists among these Angstrom found decrease in reflectance when soil moisture increases in his measurements [1]. Thereafter, familiar darkness of soil resulted by wetting of soil has been reported by other researchers [12], [3], [58], [28]. Several empirical approaches have been proposed to describe the connection between soil surface reflectance and moisture contents. Bowers and Smith [6], observed a linear relationship between the absorption in water absorption band and soil water content. Dalal and Henry, using absorbance values measured in the near infrared, estimated soil moisture with accurate results over a range of soil samples [13]. These empirical approaches, however, provide only a poor indication of soil moisture content, since the spectral characteristic of a soil also depends on numerous other factors, such as mineral composition, organic matter, soil texture, and surface roughness [2],[4], causing wide variations when they are applied to other localities outside the calibration conditions.

Jeffrey P. Walker, et al, used, Active microwave remote sensing observations of backscattering, such as C-band vertically polarized synthetic aperture radar (SAR) observations from the Second European Remote Sensing (ERS-2) satellite to measure soil moisture content at near-surface layer of soil and showed that SAR backscattering observations are highly dependent on topography, soil texture, surface roughness and soil moisture [31].

.Kolev, N.V et.al, [39] using remote sensing and ground-based measurements to measure soil moisture in agricultural areas and shows that remote sensing measurement of surface soil moisture is less sensitive in comparison with the ground-based measurements.

Brubaker and Entekhabi [7], reviewed interaction between the soil moisture and atmospheric processes and concluded that the temperature is dependent upon the surface saturation and soil moisture tends to reinforce the temperature anomalies due to major impact of soil moisture over the evaporation mechanism. Wang, has proved significant dependence of dielectric constant on soil texture keeping the same volumetric soil moisture content[69]. Many attempts have also been made to derive land surface parameters using active and passive microwave techniques [50], [61], [8]. Remotely sensed passive and active microwave signatures have certain amount of physical information in common, but each sensor is distinctly sensitive to different surface properties. Active sensors provide high spatial resolution, but are more sensitive to different surface feature such as surface roughness, type of vegetation cover and soil wetness conditions. On the other hand, passive radiometers provide high temporal resolution, but are likely to be affected by the near surface soil moisture. The difference between both the sensors is that the passive microwave radiations are less affected by the roughness parameter whereas active microwave radiations have greatly influenced by the surface parameters. The combined use of passive and active sensor observations can provide complementary information included in the land surface microwave signature [47].

Most research workers suggest that near-surface soil moisture can be retrieved with sufficient accuracy from a multichannel (i.e. multiple frequencies of polarizations) synthetic aperture radar (SAR) instrument. Although many studies have been conducted to estimate soil moisture in bare soil fields with Synthetic Aperture Radar (SAR) imagery, little success has been achieved in vegetated areas [67]. Synthetic Aperture Radar has shown its large potential for retrieving soil moisture maps at regional scales [64].

A physical model has been developed by Lobell and Asner, to explain the soil reflectance variations due to moisture change based on their analysis of the reflectance for four different soils at various moisture contents [16]. The soil reflectance at a particular wavelength is modeled as an exponential function of the volumetric soil moisture. Since experiments performed by Lobell and Asner, involved measuring soil reflectance under various moisture conditions, their model captures both the absorption and scattering effects of soil moisture [14]. Similar exponential models were proposed by Liu et al. to obtain a robust estimate of soil moisture [40]. Recently, Wang and Qu, designed the normalized multiband drought index (NMDI) for remotely sensing both soil and vegetation water content from space based on the soil and vegetation spectral signatures [68].

Gardner, in a review of methods for measuring soil water content made only passing reference to time domain reflectometry (TDR) and focused mainly on thermal gravimetric and Neutron moderation as the methods available for field investigations [25]. There are five electromagnetic techniques (EM) where new development have occurred i.e. TDR, capacitance, ground-penetrating radar (GPR), passive microwave and remote active microwave or radar. GPR reflection travel time data, where used for estimating the average volumetric water content between the ground surface and reflector. Volumetric water content estimates were obtained from GPR reflection data under dry, intermediate and saturated soil moisture conditions and the reflection was associated with a low permeability clay layer [29]. Satellite-based soil moisture can be obtained from passive microwave, active microwave, and optical sensors. Although the coarse spatial resolution of passive microwave and the inability to obtain vertically resolved information from optical sensors limit their usefulness for watershed-scale applications [45]. Better results can be obtained by combining data from optical sensors with data from thermal sensors. Thermal sensors can be used to derive surface temperature, which spatial variation is highly correlated with soil moisture variability for bare soils [57], [23]. For partially vegetated areas a combination between thermal imagery and spectral vegetation indices can improve the estimation of soil moisture.

An Artificial neural network (ANN) based methodology is used to retrieve soil moisture information with the infrared (IR) skin temperature, previous accumulated surface precipitation, and vegetation index as the input variables. ANN model has shown good performance when trained and tested with a spatially distributed dataset from different season [27].

Soil moisture contents in the unsaturated zone and depth of the groundwater level show characteristic patterns which are related to the landscape elements of the drainage basins. Kaleita, L.F et al analyzed soil surface reflectance data in the visible and near-infrared regions in conjunction with surface moisture data in a field environment to determine the nature of the relationship between the two and to identify potential methods for estimation of soil moisture from remotely sensed data at different wavelengths [37].

Tarendra Lakhankar, et.al, addresses the issue of the variability and heterogeneity problems that are expected from a sensor with a larger footprint having homogenous and heterogeneous sub-pixels in understanding of spatial variability of soil surface characteristics such as land cover and vegetation in larger footprint are critical for remote sensing based soil moisture retrieval [63]. Multi-angle radar images provide estimate of roughness and soil moisture without the use of ancillary field data and these radar images also can provide estimates of surface soil moisture at the watershed scale with good accuracy [44].

In a field observation and analysis showing that vegetation cover had significant effect on soil moisture and water table depth. Vegetation cover reduced soil moisture through evapo-transpiration, resulting in less water to recharge groundwater and therefore lowering the water table depth [73].

A hydrologic model Soil and Water Assessment Tool (SWAT) is used to develop a long-term record of soil water at a fine spatial and temporal resolution from historical weather data. Long term soil moisture information is essential for agricultural drought monitoring and crop yield prediction [49]. For sustainable use of soil and water resources information about soil moisture retention characteristics (SMRC) and hydraulic conductivity (HC) in unsaturated soils is of prime importance. Direct methods, being time consuming and expensive several textural based regression models have been used for prediction of soil moisture retention characteristics and hydraulic conductivity [52].

A review research on remote sensing of water resources indicates that there are many positive results and some techniques have been applied operationally for soil moisture estimation [54]. Presently remote sensing data is being used operationally for precipitation estimates, soil moisture measurements and surface water inventories. It is to be suggested that, in the next decade other operational applications of remote sensing techniques are likely to be used for land cover, sediment loads, erosion, groundwater and areal inputs to hydrological models.

# Soil moisture estimation

The typical remote sensing techniques used for estimation of soil moisture involve the collection and Interpretation of satellite imaging, aerial photography or ground monitoring station data regarding the nature, properties and state of the soil. These variations and differences of the soil nature, properties and state are reflected and picked by the sensors installed on the satellites depending on their different electromagnetic spectrum properties. Currently, a variety of remote sensing techniques for soil moisture estimation has been employed based on their different electromagnetic spectrum properties. A number of models have been developed by researchers to estimate the unknown soil moisture both spatially and temporally.

Remote sensing has been used to measure soil moisture for the purposes of predicting land/atmospheric water exchange and predicting agricultural performance [36]. Soil moisture estimation by remote sensing is based on either passive measurements in the microwave range of the spectrum or on the backscatter of an active radar sensor. At microwave frequencies there is a large contrast in emissivity between water and land due to the huge difference in the dielectric constant of water and soil [62]. By observing the emissivity at microwave frequencies, the water content in the soil can be estimated in a similar way from remotely sensed data as from the data obtained with dielectric in situ methods. This difference can be sensed using microwave radiometers, which allows good penetration of the soil up to one fourth of the wavelength [66]. Remotely sensed data quality depends on the sensor type (active or passive), vegetation cover, topography, surface roughness; surface temperature and soil type [70]. While remote sensing methods cannot replace ground based methods for providing high quality point data, their advantage is in mapping soil conditions at regional, continental or global scales on a repetitive basis. Active sensors can provide high-resolution data which can be used for local hydrological studies, but they are more sensitive to surface roughness, topography and vegetation than passive sensors, which in turn provide poorer resolution data and are therefore appropriate for meteorological and climate models on a global scale [60]. **Table.1** summarizes the relative merits of the different remote sensing techniques for surface soil moisture estimation.

**Table 1** Summary of remote sensing techniques for soil moisture estimation.

| Spectrum domain | | Properties observed | Advantages | Limitations |
|---|---|---|---|---|
| Optical | | Soil reflection | fine spatial resolution, broad coverage | limited surface penetration, cloud contamination, many other noise sources |
| Thermal infrared | | surface temperature | fine spatial resolution, broad coverage physical well understood | limited surface penetration, cloud contamination perturbed by meteorological conditions and vegetation |
| Microwave | passive | brightness temperature, dielectric properties, soil temperature | low atmospheric noise, moderate surface penetration<br>physical well understood | low spatial resolution,<br>perturbed by surface<br>roughness and vegetation |
| | Active | backscatter coefficient<br>dielectric properties | low atmospheric noise<br>moderate surface penetration high spatial resolution,<br>physical well understood | limited swath width perturbed by surface roughness and vegetation |

Source: Lingli Wang, John J. Qu, (2009).

Soil moisture can also be estimated by in situ measurements with more accuracy. The most reliable and accurate methods of determining soil moisture is to conduct measurements on site. These field observations also provide basis for understanding results from remote sensing techniques. The basic field methods that are most commonly used for soil moisture estimation are the (1) thermo gravimetric method (2) neutron thermalisation and (3) a group of methods based on soil dielectric properties [38]. The thermo gravimetric method estimates the water content in the soil by weighing a sample before and after drying it in the oven. The neutron method uses the ability of hydrogen to slow down fast neutrons more efficiently than other substances. In any soil, most of the hydrogen is present in water molecules and therefore the number of backscattered slow neutrons emitted from a radioactive source and measured by a detector in the probe, directly corresponds to water content in the soil. The dielectric methods are based on the large difference between the dielectric constant of water (80) and of the driest soils (less than 5). In a mixture of water and dry soil, the resulting dielectric constant is between these two extremes, thus offering a mechanism for detecting the water content in the soil [32]. Gravimetric sampling and networks of impedance probes based on dielectric methods are the two most reliable methods of estimating surface soil moisture. Since, these methods require a significant effort, both in technological as well as financial. Therefore remote sensing soil moisture observations are necessary for global applications [53], [9]. Currently, investigators obtain soil moisture content by intrusive methods, which are limited to point measurements. One of the intrusive method i.e. Ground-penetrating radar (GPR) that may eliminates the interpolation error because it can provide spatially continuous estimates of soil moisture in multi-dimensions. Apart this airborne imagery can also be used to estimate soil moisture content with meter scale resolution [36].

# Conclusion

There is a strong interest in assessing the potential of space-based monitoring and estimation of soil moisture which is an important hydrologic variable that controls various land surface processes. Soil moisture is highly variable both spatially and temporally. The spatial and temporal variation in soil moisture is resulted by variation in soil texture, vegetation, and topography and groundwater level depth. The spatial and temporal variation in soil moisture cannot be easily observed at large scales. Soil moisture at large scales can be estimated by remote sensing and hydrologic modeling. The basis of soil moisture estimation by remote sensing depends on soil surface reflectance and moisture content. The spectral characteristics of soil also depend on various factors such as mineral composition, organic matter, surface roughness and soil texture.

Remote sensing methods have not been successful in estimating soil moisture from deep soil layers, such as at the root-zone soil layers. On the basis of the active remote sensing methods, estimating soil moisture on bare soil or soil with less vegetation gives more accurate results, as compared to using the methods on a mixture of land-cover soil. Moreover, the estimation process becomes more challenging when the vegetation cover is dense. From the other side, under similar soil cover conditions, estimating soil moisture using a combination of both active and passive remote sensing information gives accurate results. Other hand, in situ soil-moisture measurements provide deep layer soil moisture estimation and are considered as the standard measurements for soil-moisture estimation. Among field methods, the standard method of measuring the soil moisture content is the thermo- gravimetric method. The advantages of this method are that it is inexpensive and soil moisture is easily calculated.

The basic conclusion of this review paper is that remote sensing combined with field methods provide distributed soil profile moisture information. It is recommended to carry out detailed research work applying both remote sensing and field measurements for soil moisture estimation.

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