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Evaluation of soil surface moisture in Dak Nong province of Vietnam by Sentinel-1 radar image

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ABSTRACT

This study focuses on monitoring the variation of surface soil moisture (0-1 cm) and ground soil moisture (0-1m) in the soil in Dak Nong province using Sentinel-1 radar images received in 21th, December, 2017. Active radar signals are utilized in this method with the principle of using short wave pulses to be sent and received. Soil moisture is calculated by measuring electromagnetic radiation in the wavelength range from 0,5 to 100 cm based on the contrast between the dielectric properties of water (~80) and soil particles (<4). With increasing humidity, the dielectric constant of the water mixture increases, this change can be detected by radar sensors. The results of moisture estimation by satellite images are checked by the results of field sampling and laboratory analysis. Radar remote sensing technique has demonstrated the ability to estimate soil moisture on the principle of correlating with actual measured data. The return scattering value of the soil consists of two components: the former is the backscattering value of the raw soil; while the latter is the backscattering value of the vegetation cover. Comparing the results of soil moisture estimation from radar images with soil moisture data measured in the field at 22 measurement points in Dak Nong and soil moisture values on the Global soil moisture Data Web site, it is found that mean deviation between calculation and measurement was 5,72% while mean deviation between calculation and SMAP is 8,14% and mean deviation between SMAP and measurement 6,8%. It is recommended that this technology should be applied to territories with complex terrain, difficult to access, and few meteorological monitoring stations.

1. Introduction

Dak Nong is located at the southwestern gateway of the Central Highlands, where is in the coordinate region from 11°45 to 12°50 north latitude and from 107°12 to 108°07 east longitude, with an average altitude of 600 to 700 meters above sea level, the highest is in Ta Dung with an altitude of up to 1,982 meters. In general, the terrain of Dak Nong runs long and lowers from east to west. The terrain is diverse, abundant and strongly dissected, alternating between high mountains, with large plateaus, gently sloping, wavy, fairly flat alternating low-lying plains (Dak Nong Provincial People's Committee, 2012).

Using remote sensing to study soil moisture was started in the mid-1970s shortly after satellite technology developed. After that, studies were conducted in many different directions, but mainly focused on using thermal imaging. Many studies now show that soil moisture can be measured by thermal infrared and optical sensors, as well as using ultra-high frequency remote sensing, both active and passive. The main differences between the methods are the electromagnetic wavelength, the source of the energy, and the physical relationship between moisture and the scattered signal (Pathe et al, 2009).

Soil moisture is calculated by measuring electromagnetic radiation in the wavelength range from 0,5 to 100 cm based on the contrast between the dielectric properties of water (~80) and soil particles (<4). With increasing humidity, the dielectric constant of the water mixture increases, this change can be detected by radar sensors. (Chen et al, 1995; Choudhury et al, 1988; Choudhury et al, 1979). Radar remote sensing technique has demonstrated the ability to calculate soil moisture on the principle of correlating with actual measured data (Dubois et al, 1994; Muller et al, 2000).

Soil moisture measurement data in the field is still minimal because direct measurement is quite complicated and expensive, therefore the results of soil moisture calculation from radar images make an essential contribution to the addition of moisture data for hard-to-reach areas. Meanwhile, using remote sensing data in general, and radar remote sensing in particular helps to quickly calculate soil moisture in many different places at the same time, including areas with difficult geographical locations, results are easily stored in the computer and ready for soil moisture analysis at any time of the year (Schmugge et al, 1983).

Dak Nong is a province with sparse meteorological monitoring stations due to difficult-to-access terrain, so the use of remote sensing images to determine soil moisture is the proper method of determining soil moisture.

This study focuses on monitoring the variation of surface soil moisture (0-1cm) and ground soil moisture (0-1m) on soil in Dak Nong province using Sentinel-1 radar images. This study result provides data for agricultural cultivation and water resource management, which is very meaningful for areas with few meteorological monitoring stations such as Dak Nong province.

Figure 1. Study area in Vietnam – DakNong Province

Table 1. Location of soil moisture measurement

No	Study sites	Coordinates		No	Study sites	Coordinates	
		Latitude	Longtitude			Latitude	Longtitude
1.	Kien Duc	11°59'49''N	107°31'40''E	12.	Nam N'Jang	12°11'46''N	107°34'37''E
2.	Dak But So	12°07'.49''N	107°24'56''E	13.	Dak Hoa	12°10'20''N	107°34'15''E
3.	DakN'Drung	12°11'46''N	107°34'37''E	14.	Truc Son	12°34'51''N	107°51'58''E
4.	QuangThanh	12°01'45''N	107°41'16''E	15.	Nam Dong	12°34'18''N	107°50'48''E
5.	Nghia Tan	11°59'57''N	107°41'21''E	16.	Duc xuyen	12°24'12''N	107°46'36''E
6.	Dak Ha	11°52'32''N	106°59'21'E	17.	Quang Phu	12°26'49''N	107°51'23''E
7.	Quang Son	11°54'59''N	106°51'56''E	18.	Dak Wil	12°34'44''N	107°51'57''E
8.	Quang Phu	12°31'44''N	107°52'17''E	19.	Dak Mil	12°27'45''N	107°37'35''E
9.	Dak Nang	12°31'13''N	107°52'27''E	20.	D ak Lao	12°27'03''N	107°37'39''E
10.	Dak Dro	12°31'18''N	107°50'11''E	21.	Duc Manh	12°27'30''N	107°37'11''E
11.	Dak Lao	12°27'03''N	107°37'39''E	22.	Dak Mam	12°25'45''N	107°52'12''E

2. Material and methodology

2.1. Material

The Sentinel-1 radar satellite images taken on December 21, 2017 in Dak Nong province were used in this study, polarized VV and VH, 5 x 20m spatial resolution, 10 x 10m pixel size. In addition, the digital elevation model ASTER (DEM ASTER) with a resolution of 30 m and a topographic map with a scale of 1:25.000 of Dak Nong province for geometry correction. Twenty-two sites in Dak nong province were selected to measure soil moisture value in the field on December 21, 2017 (Table 1.). Takemura DM 15 soil moisture meter is used to measure soil moisture. Soil moisture measurement locations in the field are illustrated in Figure 1.

2.2. Method

2.2.1. Active radar remote sensing method

Active radar signals are used with the principle of using short wave pulses to be sent and received. The intensity of the received signal is compared and obtained to determine the scattering coefficient of the surface.

The most common imaging constructs of active shortwave are synthetic aperture radar (SAR), which transmits a series of pulses that pass through a radar antenna. SAR systems can provide resolution of 10 meters over a ground width of 50-500 km. Information on radar images and soil moisture have a close relationship as shown by the interaction of dielectric constants of soil and water (Baup et al., 2007; Owe et al., 1988).

The total value of polarization scattering σ^{τ}_{pp} from the surface is the sum of the three components (Dubois et al., 1994):

$$\sigma_{pp}^{\tau} = \sigma_{pp}^{s}.\exp(-2.\tau_c) + \sigma_{pp}^{vol} + \sigma_{pp}^{int} \qquad (2.1)$$

In which:

σ^{s}_{pp} is the ground surface reflection scattering value;

τc is the two-way attenuation through the signal's vegetation;

σ^{vol}_{pp} is the scattering from the mass vegetation;

σ^{int}_{pp} is the interaction between vegetation and surface soil.

For exposed soil surface or surface with thin vegetation, σ^{s}_{pp} plays a dominant role in received signal and is influenced mainly by soil moisture and surface roughness. For areas where the vegetation layer is thick, the scattering is determined to be largely influenced by scattering from the vegetation canopy (T. Mo et al 1984).

2.2.2. Soil moisture calculation procedure

The procedure for determining soil moisture using Sentinel-1 image as illustrated in Figure 2.1

In which:

a) Orbit correction: The first step in processing the Sentinel-1 radar image is to correct the trajectory using the Apply Orbit File tool. The software will actively download the trajectory file and calibrate it.

b) Thermal noise filtering: This step eliminates the effect of backscatter disruption due to thermal noise, making data seamless especially in synthetic aperture radar processing.

c) Image calibration: The result of calibration is to provide an image where the value of the pixel is directly related to the backscatter of the object and represents the backscatter of the reflecting surface.

d) Geometric correction: is to build the relationship between the measured image coordinate systems and the standard reference coordinate system.

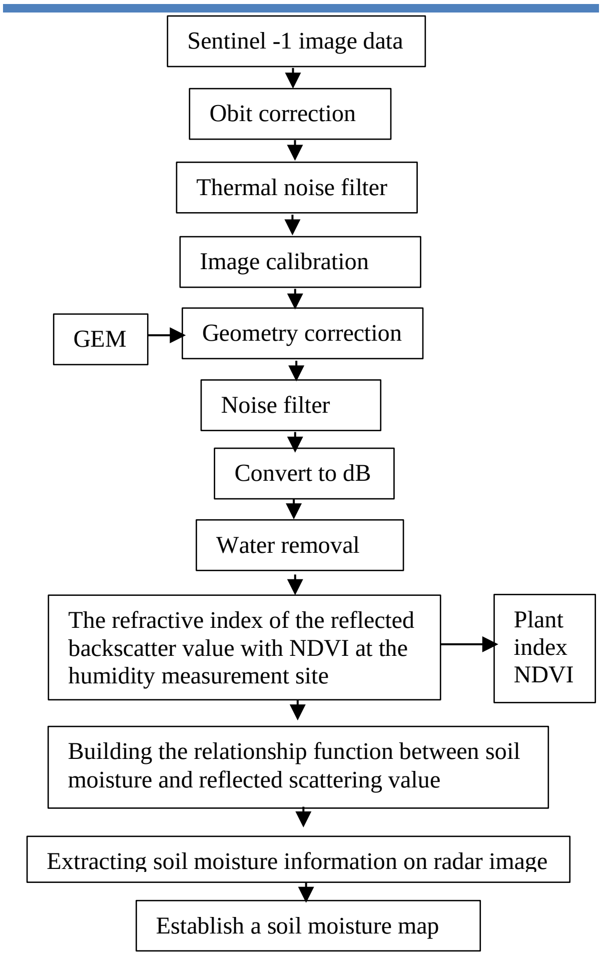


Figure 2. Soil moisture calculation procedure by Sentinel -1 radar image

j)Extraction of soil moisture information on radar images: Using a linear function coefficient of canopy

e) Noise filtering: To reduce high frequency noise (speckle), the filter used is Adaptive group with size 7x7. This group of filters does not change the local mean, but only reduces the local standard deviation.

f)Convert to dB value : The digital information of the radar image pixel is 32-bit encoded. Converting to dB values makes the value distribution uncompressed and the normal distribution makes the analysis easier.

g) Water removal: Use SNAP's water separation tool to separate the water area. Then overlay with the converted radar image dB value to create the final product of the image processing.

h) Extract scattering value back with NDVI at soil moisture measurement location: Use GIS software like QGIS to overlay images, NDVI vegetation index images and measuring points to extract scattering values at measurement points.

i) Building the relationship function between soil moisture and backscattering value: To determine the relationship function between the backscatter value on the image and the soil moisture value, it is necessary to extract the backscattering value for the soil moisture at each measurement location.

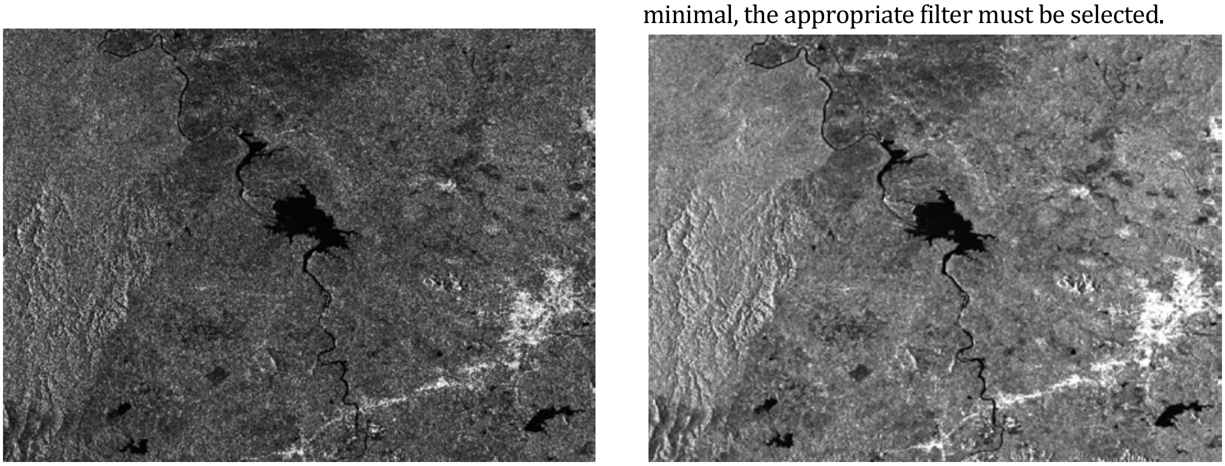
values that respond to soil moisture and NDVI calculates moisture values for the whole image.

k) Establishing soil moisture map: Base on soil moisture calculation, thresholding and editing soil moisture map by ArcGIS software.

3. Results and discussion

3.1. Result of soil moisture estimation procedure by Sentinel -1 radar image

Sentinel-1 data after the geometric correction has ensured the following criteria: (1) Better discrimination of objects on the image, (2) pixel classification and structure classification, (3) preservation to ensure that information loss is minimal, the appropriate filter must be selected.



a) Before noise filtering b)After noise filtering

Figure 3. Image noise filter results

Fig.3a is before image noise filtering and Fig.3b is after image noise filtering. After conversion, the radar data is converted to dB value and removed from the water area for the scattering value calculation. Then the backscatter value is extracted together with the NDVI vegetation index, the image overlay QGIS software is used to extract the scattering value at the measurement point. Due to the backscatter value of the surface will represent the moisture content of the vegetation and the soil moisture, the NDVI vegetation index is used as a parameter to calculate the actual soil moisture value, obtain the calculation function, soil moisture with standard deviation of 7.3%, specifically as follows:

$$Soil\ moisture = 85{,}877407 + 5{,}109456.\sigma^0 - 18{,}348833.NDVI \qquad (2.2)$$

After obtaining the humidity values, proceed to thresholding, editing and creating a moisture map using ARC GIS software. For crops, threshold values are divided into levels from 0-10%, 10-20%, 20-30%, 30-40% and greater than 40%. The established soil moisture map tends to be naturally suitable according to the topographical structure of the area: low humidity corresponding to high terrain area, and vice versa, high humidity with low terrain or streams. Fig. 4 is Map of soil moisture estimated from Sentinel -1 radar image of Dak nong province.

3.2. Assess accuracy of the soil moisture estimation results by Sentinel -1 radar image

Comparing the results of soil moisture estimation from radar images with soil moisture data measured in the field at 22 measurement points in Dak Nong and soil moisture values on the Global soil moisture Data Web site https://www.earthdata.nasa.gov/, it is found that mean deviation between calculation and measurement was 5,72 % while mean deviation between calculation and SMAP is 8,14 % and mean deviation between SMAP and measurement 6,8 %. These results are shown in Table 2.

According to F. Baup (2007), the results of the humidity test conducted by one person under the same test conditions, the coefficient of difference is 2,7%; and results by different laboratories have a coefficient of difference of 5%. Refer to this research, it can be asserted that calculated from radar sentinel -1 soil moisture values applied for Dak nong province are completely satisfactory within certain limits.

Table 2. Compare values of soil moisture

No	Study sites	Measured soil moisture (%)	SMAP soil moisture (%)	Calculated soil moisture (%)	Deviation between calculation and measurement	Deviation between calculation and SMAP	Deviation between SMAP and measurement
1.	Kien Duc	12,23	15,6	19,32	7,09	3,72	3,37
2.	Dak But So	15,3	12,8	16,18	0,88	3,38	-2,5
3.	DakN'Drung	34,33	44	31,83	-2,5	-12,17	9,67
4.	QuangThanh	28,42	33	20,81	-7,61	-12,19	4,58
5.	Nghia Tan	15,67	20,5	20,75	5,08	0,25	4,83
6.	Dak Ha	17,29	20,5	21,21	3,92	0,71	3,21
7.	Quang Son	15,35	21,8	17,89	2,54	-3,91	6,45
8.	Quang Phu	18,5	24	29,39	10,89	5,39	5,5
9.	Dak Nang	29,68	24	29,88	0,2	5,88	-5,68
10.	Dak Dro	34,47	27,8	34,67	0,2	6,87	-6,67
11.	Dak Lao	12,24	18,6	17,42	5,18	-1,18	6,36
12.	Nam N'Jang	22,74	33	20,81	-1,93	-12,19	10,26
13.	Dak Hoa	23,02	33,3	18,24	-4,78	-15,06	10,28
14.	Truc Son	18,02	23,1	28,82	10,8	5,72	5,08
15.	Nam Dong	13,18	19,5	21,12	7,94	1,62	6,32

16.	Duc xuyen	44,27	57,48	38,64	-5,63	-18,84	13,21
17.	Quang Phu	38,09	43,4	35,26	-2,83	-8,14	5,31
18.	Dak Wil	28,02	42,8	26,56	-1,46	-16,24	14,78
19.	Dak Mil	29,89	24,8	23,77	-6,12	-1,03	-5,09
20.	D ak Lao	25,23	21,5	24,13	-1,1	2,63	-3,73
21.	Duc Manh	28,51	18,6	29,05	0,54	10,45	-9,91
22.	Dak Mam	26,45	20,5	17,28	-9,17	-3,22	-5,95

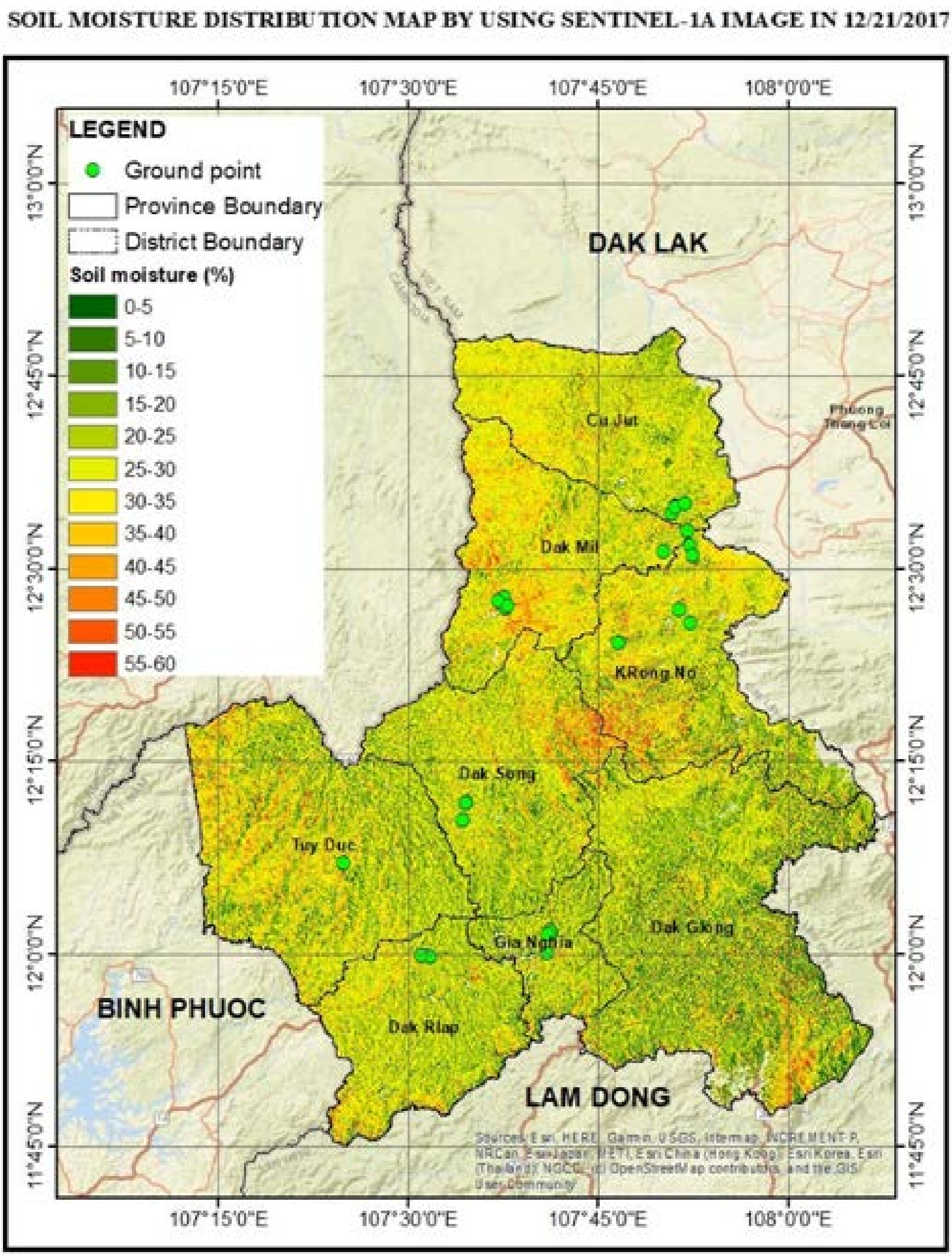


Figure 4. Soil moisture distribution map of Dak Nong province by using Sentinel -1 radar image.

4. Conclusion

The results from this study proves that it is possible to extract the surface soil moisture in Dak Nong province quickly and objectively by using Sentinel - 1 radar image. It is necessary to takes soil moisture measurement value at some points in the field combined with radar data to estimate soil moisture. From these values, based on the relationship between soil moisture and the reflected scattering signal of the radar image, we can estimate the soil moisture value for a large area with satisfactory accuracy. Research results have shown that using radar satellite images to extract soil moisture information brings many advantages. However, the extraction of the backscattering value at the measurement sites is a crucial work step. The return scattering value of the soil consists of two components, one is the backscattering value of the raw soil and the backscattering value of the vegetation cover. It is recommended that this technology should be applied to territories with complex terrain, difficult to access, and few meteorological monitoring stations.

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Contribution of authors

Thao Thi Phuong Vu and Phi Quoc Nguyen - contribute to the idea, data acquisition, analysis, and writes the manuscript; Cuong Cao Do- contribute to collecting the data.

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