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Evaluation of soil surface moisture in Dak Nong province, 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÷1 m) in the soil in Dak Nong province using Sentinel-1 radar images received in December 2017. Active radar signals utilized in this method were sent and received using short wave pulses. The intensity of the received signal is compared 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. Soil moisture is calculated by measuring electromagnetic radiation in the wavelength range from 0.5÷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. It is recommended that this technology should be applied to territories with complex, difficult-to-access terrains and few meteorological monitoring stations.

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1. Introduction

Dak Nong is located at the southwestern gateway of the Central Highlands, which is in the coordinate region from $11^0 45 \div 12^0 50$ north latitude and $107^0 12 \div 108^0 07$ east longitude, with an average altitude of 600÷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, and 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 had been 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 both active and passive ultra-high frequency remote sensing. 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÷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 and Golus, 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 and Van Zyl, 1994; Muller and Decamps, 2000).

Soil moisture measurement data in the field is still minimal because the 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 help 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, 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÷1 cm) and ground soil moisture (0÷1 m) on soil in Dak Nong province using Sentinel-1 radar images. The study results provide data for agricultural cultivation and water resource management, which is very meaningful for areas with few meteorological monitoring stations such as Dak Nong province.

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 20 m spatial resolution, 10 x 10 m pixel size. In addition, the Advanced Spaceborne Thermal Emission and Reflection Radiometer Global digital elevation model (ASTERGDEM) with a resolution of 30 m and a topographic map with a scale of 1:25,000 of Dak Nong province were applied 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 was 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 used in this study were sent and received with the principle of using short wave pulses. The intensity of the received signal was compared 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 a resolution of 10 m over a ground width of 50÷500 km.

Table 1. Location of soil moisture measurement.

No	Study sites	Coordinates		No	Study sites	Coordinates	
		Latitude	Longitude			Latitude	Longitude
1	Kien Duc	11^{0}59'48.9844"N	107^{0}31'4.017"E	12	Nam N'Jang	12^{0}11'46.1112"N	107^{0}34'37.1622"E
2	Dak But So	12^{0}7'0.4894"N	107^{0}24'55.7003"E	13	Dak Hoa	12^{0}10'20.6368"N	107^{0}34'15.9964"E
3	DakN'Drung	12^{0}11'46.0885"N	107^{0}34'37.182"E	14	Truc Son	12^{0}34'51.1241"N	107^{0}51'8.8668"E
4	QuangThanh	12^{0}1'44.868"N	107^{0}41'15.7214"E	15	Nam Dong	12^{0}34'18.2521"N	107^{0}50'48.0872"E
5	Nghia Tan	11^{0}59'56.9566"N	107^{0}41'2.126"E	16	Duc xuyen	12^{0}24'12.515"N	107^{0}46'36.7234"E
6	Dak Ha	11^{0}52'32.33"N	106^{0}59'21.56"E	17	Quang Phu	12^{0}26'49.4268"N	107^{0}51'22.8485"E
7	Quang Son	11^{0}54'59.98"N	106^{0}51'56.1"E	18	Dak Wil	12^{0}34'44.325"N	107^{0}51'7.672"E
8	Quang Phu	12^{0}31'44.5166"N	107^{0}52'16.9608"E	19	Dak Mil	12^{0}27'45.22"N	107^{0}37'35.114"E
9	Dak Nang	12^{0}31'1.375"N	107^{0}52'27.08"E	20	D ak Lao	12^{0}27'0.3272"N	107^{0}37'39.0414"E
10	Dak Dro	12^{0}31'18.7194"N	107^{0}50'11.2787"E	21	Duc Manh	12^{0}27'30.45"N	107^{0}37'1.141"E
11	Dak Lao	12^{0}27'0.3272"N	107^{0}37'39.0414"E	22	Dak Mam	12^{0}25'45.55"N	107^{0}52'12.4555"E

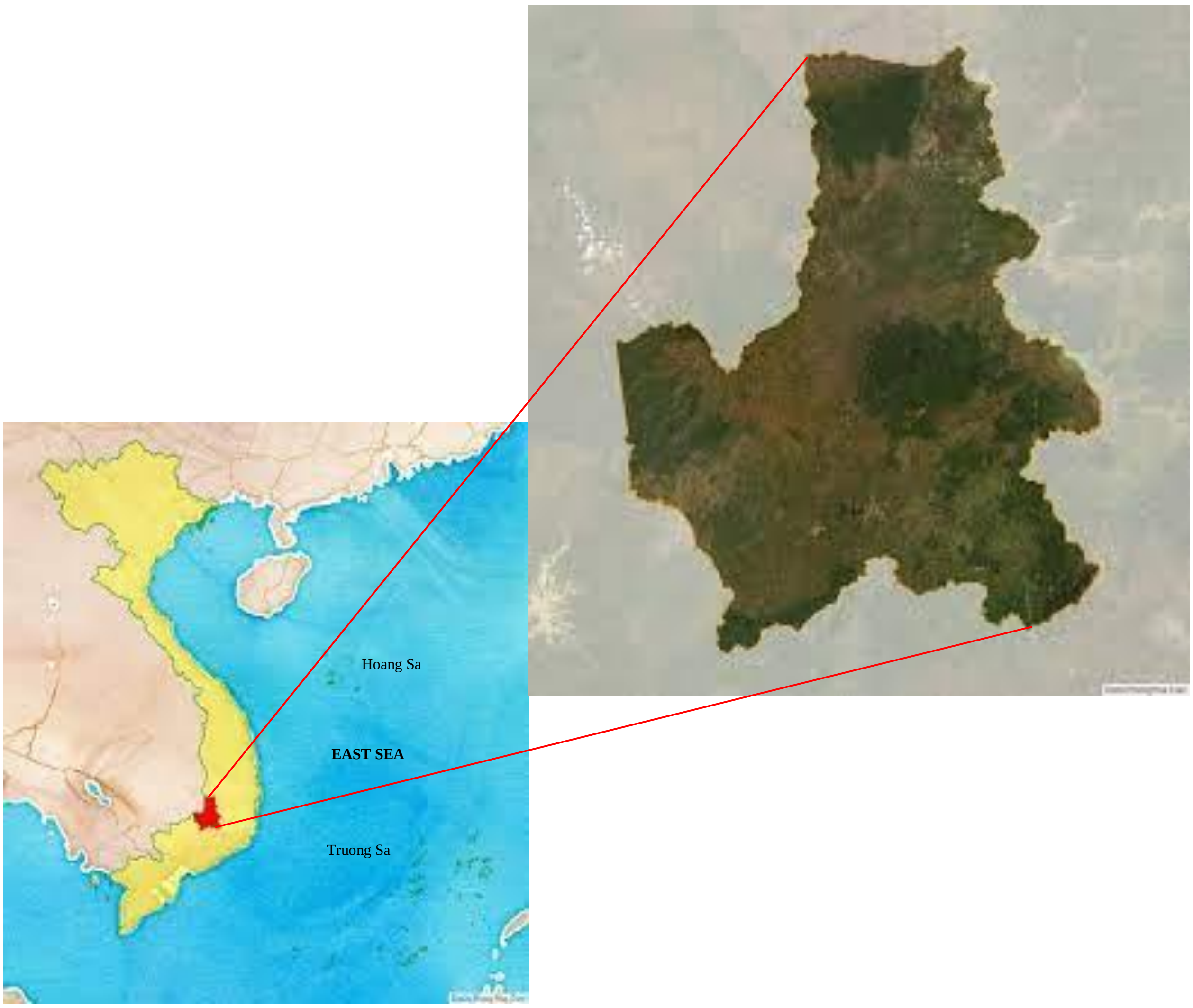

Figure 1. Study area in Vietnam.

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 and Van Zyl., 1994) as shown in equation (1).

$$\sigma_{pp}^{\tau} = \sigma_{pp}^{s}\, exp(-2.\tau_c) + \sigma_{pp}^{vol} + \sigma_{pp}^{int} \qquad (1)$$

In which: σ^{s}_{pp} - the ground surface reflection scattering value; τc is the two-way attenuation through the signal's vegetation; σ^{vol}_{pp} - the scattering from the mass vegetation; σ^{int}_{pp} - the interaction between vegetation and surface soil.

For exposed soil surface or surface with thin vegetation, σ^{s}_{pp} plays a dominant role in the 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 (Mo et al., 1984).

2.2.2. Soil moisture calculation procedure

The procedure for determining soil moisture using Sentinel-1 image is illustrated in Figure 2.

In which:

a) Orbit correction: Collected Sentinel-1 satellite data including orbital correction file. Therefore, 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 effects 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. With the information of the satellite manufacturers, the image of sigma-nought scattering coefficient values will be generated from the calibration process.

d) Geometric correction: This step aims to build the relationship between the measured image coordinate systems and the standard reference coordinate system. In this study, radar image data is used to extract moisture value from the reflected scattering value on the image.

e) Noise filtering: The Adaptive group filter with size 7x7 is used to reduce high-frequency noise (speckle). This group of filters does not change the local mean but only reduces the local standard deviation, the main purposes are as follows: (1) the image is smoother than the original image while structured boundaries are preserved;

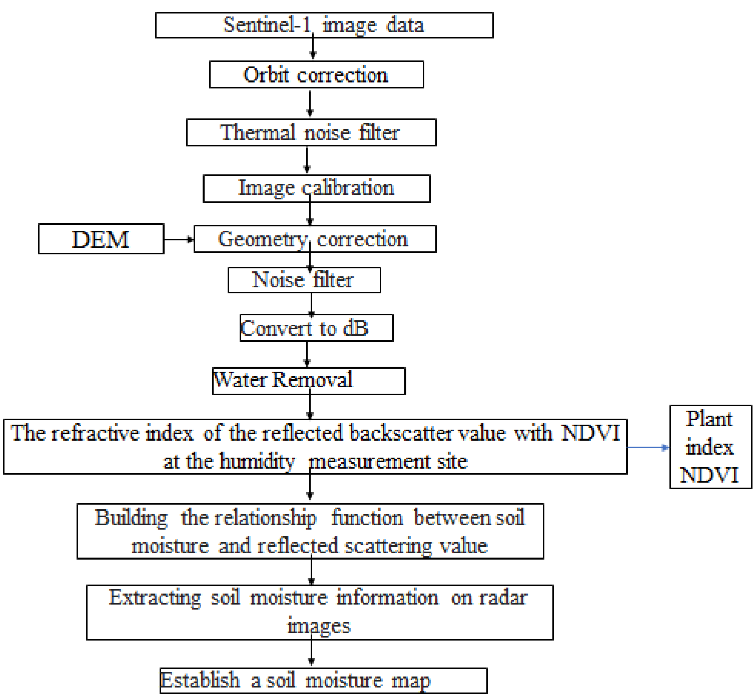

Figure 2. Soil moisture calculation procedure by Sentinel -1 radar image.

(2) the objects on the image are better distinguished; (3) the classical enhancement tools can be applied for optical images such as boundary delimiters, pixel classifiers and structure classifiers; (4) the change detection can be analyzed.

f) Convert to dB value: The digital information of the radar image pixel is 32-bit encoded. This data often has a low distribution near zero, so the data is compressed, making it very difficult to be analyzed. Converting this data to dB values makes the value distribution uncompressed and the normal distribution makes the analysis easier. The result of this process is that the radar image is converted to a dB value.

g) Water removal: The removal of water helps the moisture analysis process avoid interference caused by the water surface. The SNAP's water separation tool is used to separate the water area. Then, the data are overlaid with the converted radar image dB value to create the final product of the image processing.

h) Extraction of scattering value back with NDVI at soil moisture measurement location: GIS software like QGIS is used to overlay images; NDVI vegetation index images and measuring points are utilized to extract scattering values at measurement points.

i) Establishment of 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 content at each measurement location.

j) Extraction of soil moisture information on radar images: A linear function coefficient of canopy values that respond to soil moisture and NDVI is used to calculate moisture values for the whole image. This process result is an image of moisture in percent (%).

k) Establishment of soil moisture map: Based on soil moisture calculation, a soil moisture map is thresholded and edited 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, and the appropriate filter must be selected.

Figure 3a is before image noise filtering and Figure 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, and the image overlay QGIS software is used to extract the scattering value at the measurement point. Due to the backscatter value of the surface which 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,

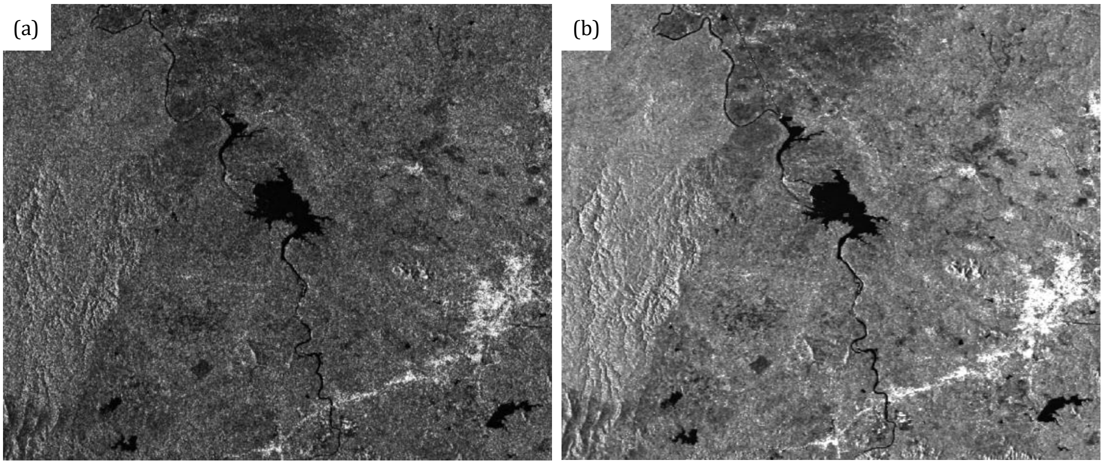

Figure 3. Image noise filter results. a) Before noise filtering; b) After noise filtering.

and obtain the calculation function, soil moisture with a standard deviation of 7.3%, specifically as in equation (2) following:

$$Soil\ moisture=86.877407+5.109456*Sigmanought-18.348833*NDVI \quad (2)$$

After the humidity values are obtained, it is necessary to threshold, edit, and create 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 corresponds to a high terrain area, and vice versa, high humidity with low terrain or streams. Figure 4 is the map of soil moisture estimated from Sentinel -1 radar image of Dak Nong province.

3.2. Accuracy assessment of the results of soil moisture estimation by Sentinel -1 radar image

When the results of soil moisture estimation from radar images are compared 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. bgov/, it is found that the mean deviation between calculation and measurement is 5.72 while the mean deviation between calculation and SMAP is 8.14 and the mean deviation between SMAP and measurement is 6.8. These results are shown in Table 2.

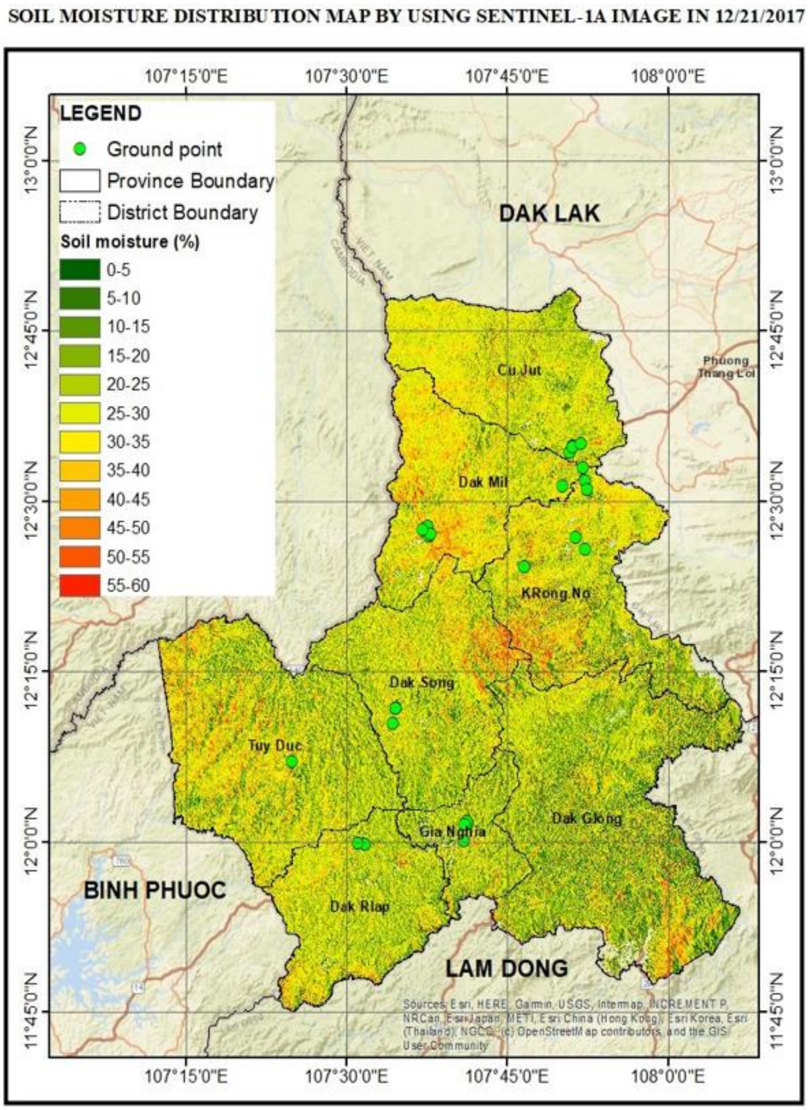

Figure 4. Soil moisture distribution map of Dak Nong province by using Sentinel -1 radar image.

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

According to Baup et al. (2007) the results of the humidity test conducted by one person under the same test conditions have a coefficient of difference of 2.7%; and the results by different laboratories have a coefficient of difference of 5%. Therefore, it can be asserted that soil moisture values calculated from radar sentinel -1 applied for Dak Nong province are completely satisfied within certain limits.

4. Conclusion

The results from this study prove 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 take soil moisture measurement values 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 other is the backscattering value of the vegetation cover. It is recommended that this technology should be applied to territories with complex and difficult-to-access terrains and few meteorological monitoring stations.

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Contribution of authors

Thao Phuong Thi Vu and Phi Quoc Nguyen - methodology, data acquisition, analysis, and writing the manuscript; Cuong Cao Do - collecting the data.

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