SOIL MOISTURE ESTIMATION BASED ON WATER CLOUD MODEL AT THE MOUNTAINOUS AREA

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ABSTRACT: Soil moisture is a key factor in water cycle. It shows a water movement in the land surface which is a boundary between atmosphere and ground. Many researches proved that the applicability of soil moisture data on various fields such as drought monitoring, agricultural productivity and climate change analysis. Because of this importance, many studies have been conducted to accurately and effectively estimate soil moisture. Satellite-based soil moisture data is more representative of space and more economical than field measurements, so satellites are very promising as a method of measuring soil moisture. However its coarse spatial resolution is pointed out as a limit and also the reliability becomes deteriorated in specific environment, for example mountainous area with complex topography and thick vegetation cover. To overcome these drawbacks, this study is conducted for estimation of soil moisture with high spatial resolution on Korean peninsula using Sentinel-1 satellite data which has finer spatial resolution (10m~1km). But until now, soil moisture estimation on mountainous area with Sentinel-1 data is considered inaccurate due to the sensitivity of backscattering coefficient of Sentinel-1 data appears too high on mountainous area. According to precedence studies, backscattering coefficient of Sentinel-1 data could show the change of soil moisture if the influences of other factors are considered. Because the land cover of the Korean Peninsula is mainly composed of mountain, it is necessary to consider error sources caused from mountain to estimate soil moisture. In this study, the error source of soil moisture estimation on Korean mountainous area is analyzed by considering of vegetation cover and water cloud model using in-situ and Sentinel-2 datasets. The incidence angle normalization and surface roughness sensitivity analysis are also conducted for minimizing the impact of surface roughness. The results of this study compare optimized soil moisture estimation method with other soil moisture products on Korean mountainous area. This study would be the base for improvement of soil moisture estimation algorithm on the Korean peninsula.

1. INTRODUCTION

Soil moisture observation measurements has been assumed as important for hydrology research and many other scientific fields (Zan et al., 2018). Most classic way to measure soil moisture is gravimetric method. But this method is not appropriate for monitoring of soil moisture. Then the development of frequency domain reflectometry sensor (FDR) and time domain reflectometry (TDR) sensor make fast, reliable and automated soil moisture monitoring become possible (Skierucha et al., 2010). Even though these dielectric sensors are convenient to measure soil moisture, this method also has a limit to monitoring spatial soil moisture data. To overcome this problem, remote sensing technology to measure soil moisture on the ground was required.

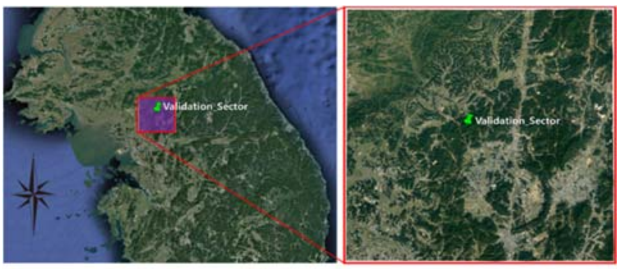
Since 1970s, soil moisture estimation using remote sensing data has been conducted. Especially, satellite received attention as promising tool for soil moisture estimation for its economic advantage and availability of spatially representative soil moisture estimation. At first, passive microwave sensor was developed and set up on the satellite. The characteristic of passive microwave sensor data is dense temporal resolution and coarse spatial resolution. And also the data from passive microwave sensor is largely affected by vegetation and weather condition (Njoku et al., 1996). Passive microwave sensor was proved its reliability with many studies, however the coarse resolution of the data was pointed out as the biggest limit for application of the satellite based soil moisture data. Because of that reason, high spatial resolution soil moisture data is required.

Synthetic Aperture Radar (SAR) data has very high resolution (10m-1km) which is using active microwave sensor. And some verifications are reported that satellite based SAR sensor is available to estimate soil moisture content on the ground surface (Engman and Chauhan., 1995). According to the theory, backscattering value from SAR sensor is closely related to dielectric constant. Water in the soil is increasing dielectric constant of the soil and it results in strong reaction of the backscattering signal (Moran et al., 2000). But the backscattering signal is also affected by vegetation and surface roughness. This is obviously appears on the mountainous areas which have both traits, thick vegetation and bumpy surface. So the many studies using SAR data to observe soil moisture are done on the bare soil areas or sparsely vegetated areas.

In that point of view, Korea which has more than 50 % mountainous area among whole country is necessary for its own optimized soil moisture retrieval method to estimate soil moisture from satellite based SAR data. Furthermore, according to some studies, radio frequency interference (RFI) and thickly vegetated surface are main obstacles for active and satellite based passive microwave sensor data application on Korea peninsula (Choi et al., 2011). And also with the reliable high resolution soil moisture data, it is possible to analyze water related disasters occurred in local area more specifically.

So in this study, soil moisture estimation at Korean mountainous area is conducted. At first based on Water Cloud Model, relation between soil moisture, backscattering signal and vegetation is analyzed on thickly vegetated area. And then the semi-empirical methods are conducted for estimation of soil moisture with physical based parameters. As a result, soil moisture product from SAR sensor is presented with considering of vegetation on the ground.

2. STUDY AREA



	Lat. (degree)	Lon. (degree)	Elevation (m)	Depth (cm)
FDR1	37.9390	126.9548	291	10,20,30,40
FDR2	37.9394	126.9566	327	10,20,30,40
FDR3	37.9393	126.9566	329	10,20,30,40
FDR4	37.9393	126.9565	318	10,20,30,40
FDR5	37.9386	126.9566	349	10,20,30,40
FDR6	37.9385	126.9567	373	10,20,30,40
FDR7	37.9384	126.9566	357	10,20,30,40
TDR	37.9375	126.9514	268	10,30,60

Figure 1. Study site and in-situ data location

Study Area of this research is mountainous area in Paju city, South Korea. Total 6 Sentinel-1 images are used which including 8 in-situ sites consist with 7 FDR sensor and 1 TDR sensor. Geographical features of the study area make hard measure soil moisture with both in-situ and remote sensing measurements. Especially for vegetation, this area has very thick vegetation cover over the ground surface. As a result, backscattering coefficient data from SAR sensor is strongly affected by mountainous topography.

To consider vegetation and roughness of the area, Local Incidence Angle (LIA) and Normalized Difference Vegetation Index (NDVI) are collected on the study area. Data used in this study are collected by satellite based SAR sensors.

3. DATASETS

In this study, Sentinel-1 and Sentinel-2 satellite data are used. Satellite data are downloaded from website managed by European Agency. (http://scihub.Copernicus.eu/) First, for sentinel-1 data SNAP application is used for preprocessing. Orbit file applying and radiometric calibration of signal is done for first step. And speckle filtering and terrain correction is conducted. Speckle filtering is for preservation of the polarimetric properties of vertical receiving and vertical transmitting (VV) polarization SAR data. In the terrain correction step, spatial resolution of the data is set to 10m.

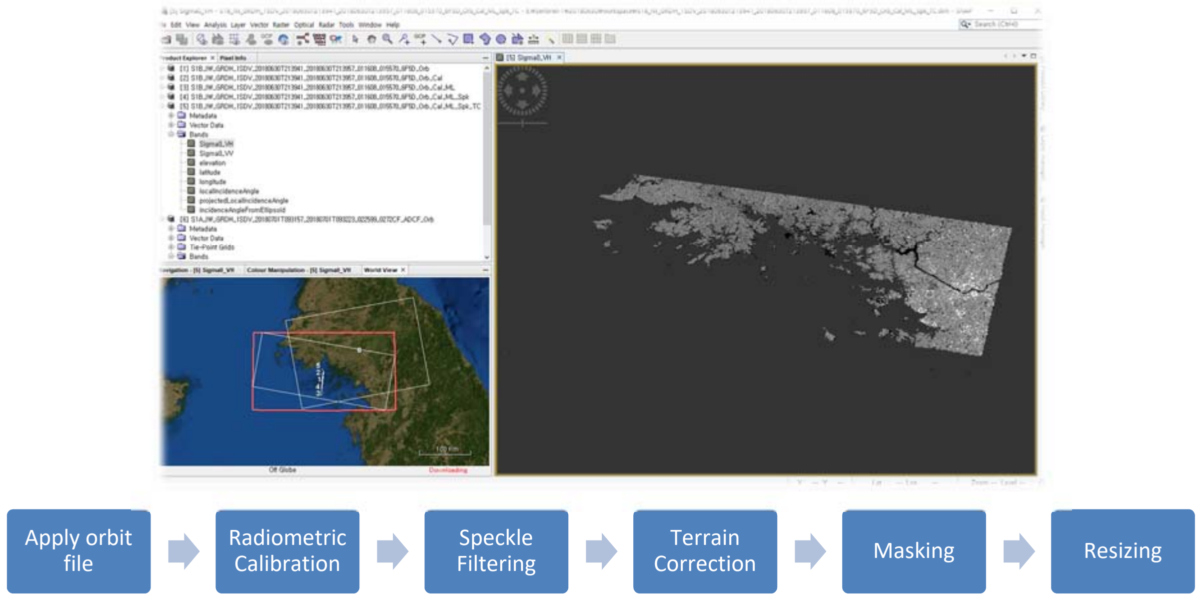


Figure 2. SNAP application for preprocessing and preprocessing steps

Second, for Sentinel-2 data, SNAP application also used. In the first step of preprocessing, resampling of Sentinel-2 data is done and atmospheric correction is conducted using SEN2COR plugin provided by ESA. NDVI is calculated from SNAP application using NIR band and Red band of Sentinel-2 data (equation 1).

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

In the resampling step, spatial resolution of data is set to 10m which is same size with Sentinel-1 data for the soil moisture mapping. And the purpose of atmospheric correction of Sentinel-2 data is quality control of high spectral sensor data (Drusch et al., 2012).

4. METHOD

On the first step to accomplish objective of this study, relation analysis between backscattering coefficient and soil moisture on mountainous area must be conducted. According to the WCM, backscattering signal on the surface is broadly divided into 2 signals (Bindlish et al., 2001; equation 2).

$$\sigma^0 = \sigma^0{}_{veg} + T^2 \sigma^0{}_{soil} \tag{2}$$

σ^0 is backscattering signal, and in the equation there are 2 signals from soil and vegetation. WCM assumes forest as horizontal cloud on the ground and with this equation we could know that in the backscattering signal from thick forest, signal generated by vegetation would be main noise source.

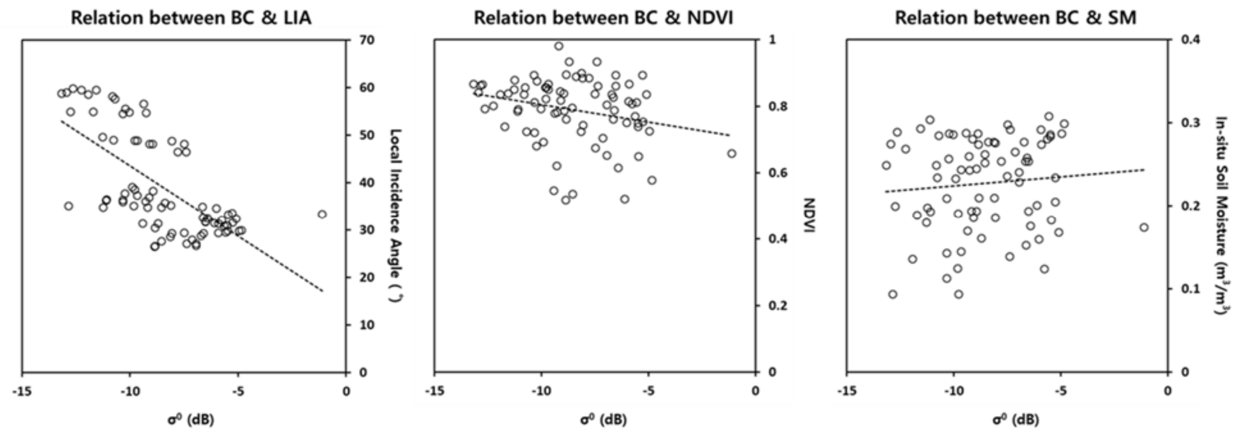


Figure 3 Relation Analysis of Backscattering, Soil moisture and NDVI

Figure 3 shows that backscattering signal has linear relationship with soil moisture and inverse proportion with NDVI. And also the backscattering and LIA is also shows an inverse proportion.

Based on these results polynomial equation and Hougen nonlinear equation is built for estimation of soil moisture on SMC site with physical parameters deeply related with soil moisture (LIA and NDVI). (3), (4)

$$\begin{aligned} SSM = const + c_1\sigma_0 + c_2 VI + c_3 \sec(\theta) + c_4\sigma_0 VI + c_5 VI\sec(\theta) \\ + c_6\sigma_0\sec(\theta) + c_7\sigma_0 2 + c_8 VI^2 + c_9\sec^2(\theta) \end{aligned} \tag{3}$$

$$SSM = \frac{(b_1 \times x_2 - \frac{x_3}{b_5})}{(1 + b_2 \times x_2 + b_4 \times x_3)} \tag{4}$$

Coefficients of each equation is calculated with 48 samples. For considering of vegetation on the study area, the factors used in Water Cloud Model to get rid of vegetation effect are gathered for variables in Multi-variate polynomial regression formula (Bao et al., 2018; equation 3) And Hougen nonlinear regression method is used with backscattering (equation 4). 2 nonlinear regression methods are tried in this study to find best regression method on Korean mountainous area.

5. RESULTS

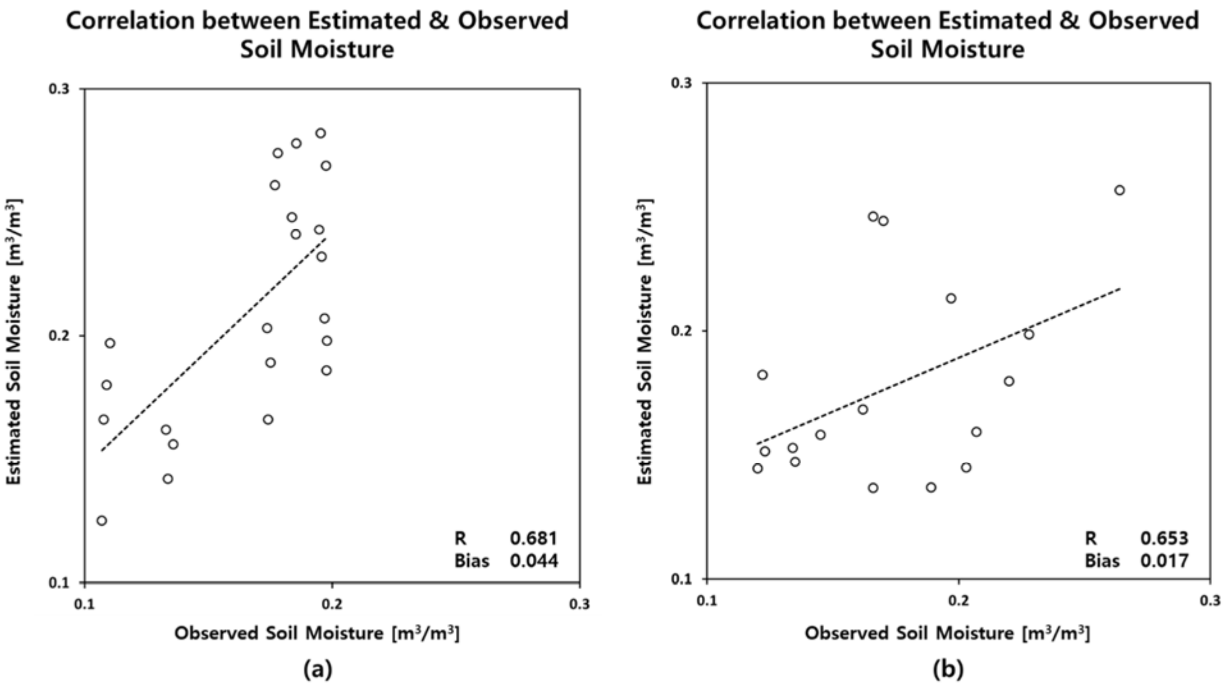


Figure 4. (a) is result of Hougen method and (b) is result of Multivariate polynomial regression method

The correlation between observed soil moisture dataset and estimated soil moisture from Hougen nonlinear regression method and Multi-variate polynomial regression method are shown on figure 4. R value of figure 4. (a) is 0.6813 and (b) is 0.6533. On July to August, Korean peninsula was initial summer season. According to the KMA, in this period Korea peninsula has less precipitation and dry air and strong sunlight were dominant on this region. On this point of view, low value (%) of soil moisture over the study area is acceptable for both graphs. Even though the area was totally covered with mountains, the R value was robust. And also the backscattering signal is highly sensitive to the thick vegetation and roughness, the result shows scientifically affordable bias (0.044 for Hougen and 0.017 for polynomial regression).

The R value is slightly higher on the Hougen method. So the mapping of soil moisture is conducted by using Hougen Method (Figure 5). Also on the mapping images, mostly low soil moisture is appeared. And because of the weather interference to the Sentinel-2 images, some gaps are shown on the images. This limitation could be solved by cloud screening in future study.

6. CONCLUSION

In this study, soil moisture estimation on the mountains using NDVI from Sentinel-2 satellite, LIA and backscattering signal from the SAR data shows reasonable soil moisture estimation results on Korean peninsula using 2 method. First based on WCM, physically related parameters with backscattering coefficient is selected and analyzed. Then with Hougen nonlinear regression and Multi-variate polynomial regression methods are done and compared. Inter-comparison with in-situ soil moisture and estimated soil moisture is conducted also. As a result, R value of result from Hougen method shows better than Multi-variate polynomial regression method. Finally mapping of soil moisture on SMC site with Hougen method is conducted.

But the obstacles for estimation of soil moisture has been identified. At first, on the analysis

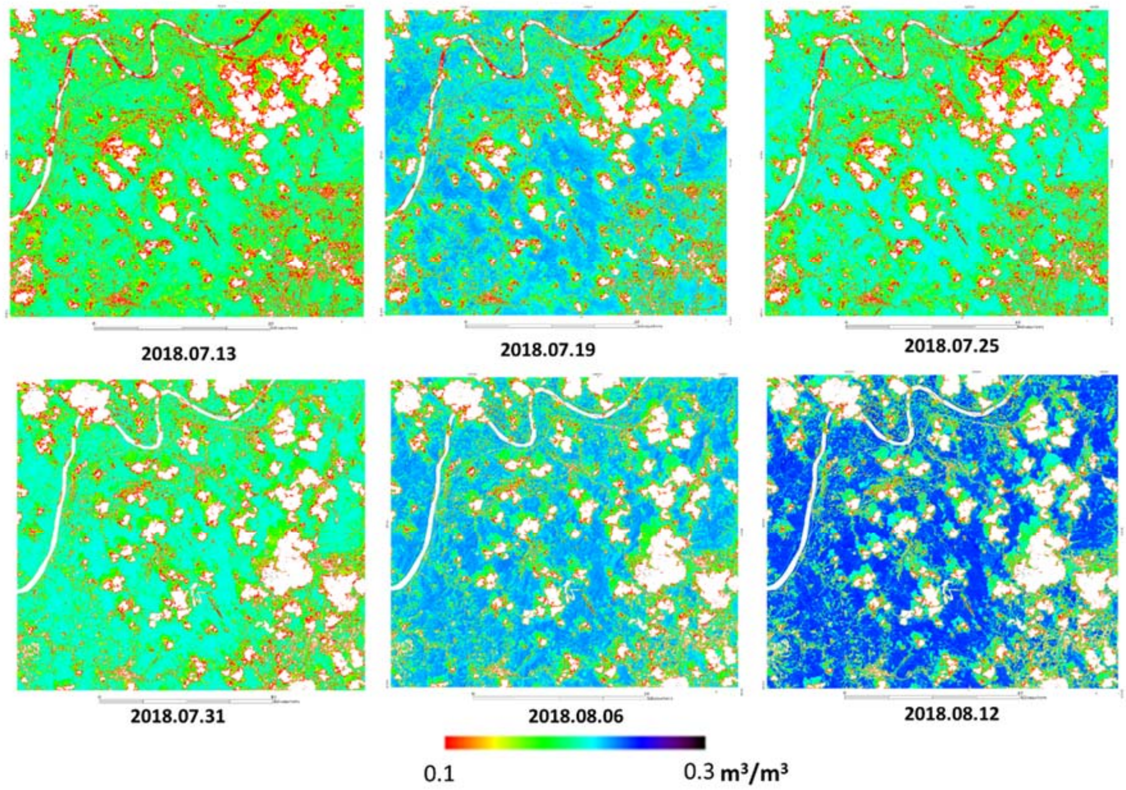


Figure 4. Soil Moisture mapping using SAR data

between backscattering signal and physical parameters, it seems that the effect of parameters for signal is almost same or bigger than the soil moisture on the mountainous area. More detail analysis and decomposition method for getting rid of influences from parameters should be developed. The roughness and thick vegetation on the ground make still null values. Considering of these error sources should be studied. Also the vegetation index from Sentinel-2 images have interferences occurred by cloud. Screening of cloud and interpolation of NDVI value would be conducted in future study. Furthermore, initially WCM model is using Vegetation Water Content (VWC). NDVI has linear relationship with VWC but they are different. So Normalized Difference Water Index (NDWI) which is known as representative index for VWC would be tested as a parameter (Huang et al., 2005).

In the future study, to overcome these problems, image of Sentinel-1 from late 2018 to present could be used which has 6 days temporal resolution. Also the different local incidence angles effect on the data would be analyzed. And the suggestion of precedence study (Bao et al 2018), Sentinel-2 images shows better performance than Landsat-8 data. Preprocessing code for Sentinel-2 images would be ready for next step.

And the factors used in this study will be applied for more various regression and physical based models. The progress of this study could develop the proper method for soil moisture estimation on mountainous area.

7. ACKNOWLEDGEMENT

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