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Estimated Soil Moisture on Paddy Field in Indramayu by Using RADAR Image

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Abstract

Availability of soil water is the main determinant in agricultural production, including rice paddy. Therefore, the information of soil moisture becomes very important in planning of water control as a part of rice cultivation management to ensure the availability of water for plants. This paper aims to describe the model of moisture estimation on paddy field, whether it is bare soil or planted with rice. The estimation of soil moisture on paddy field that had variation of moisture and growth condition of rice was conducted by using RADARSAT 2 quad polarized high resolution images. The approximation approach of this model used the assumption that coefficient backscatter of RADAR was contributed from soil and crop covered the soil that influenced by two way attenuation. The research used data of 56 field observations in bare soil and 38 field observations in rice planted land. Subsequently, relationships between the measured soil moisture (volumetric) and each backscatter coefficients (in dB) in single bands of HH, HV, VH, and VV were obtained by using a simple regression equation. Soil moisture of the bare soil was carried out by inversion of the equation between the backscatter coefficient and the measured soil moisture. Whereas in rice planted land soil moisture is reached by inversion of the equation between the coefficient of backscatter and measured soil moisture that had accommodated the present of soil backscatter, crop backscatter and the two way attenuation. The result of this research showed that the regression equation models using HH polarization gave the best result with highest R2 value and lowest the Root Mean Square Error (RMSE) value on both bare soil and rice planted land

Keywords: Backscatter coefficient; Soil moisture; Polarization; Paddy field

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Introduction

Water is a very important part of plant growth for about 60 percent. Therefore, the water content in the soil (soil moisture) as a medium for growing plants is very important in agricultural cultivation. The availability of water becomes main determinant in production of agriculture commodity, including rice paddy. Paddy is a kind of crop that requires huge water. Therefore, water control becomes very important in the management of rice cultivation to ensure the availability of water for plants. Thus the information of soil moisture and its distribution is very important in planning water control, especially to estimate the availability and need of water plant growth. Furthermore, this information is very useful in planning water control on agricultural land to provide the needs of crops effectively and efficiently.

Conventionally, soil moisture information can be retrieved by the measurement on the location site, but it is difficult to apply in large areas of land. The soil moisture differs spatially from one to another location and it may change periodically. Estimation of soil moisture in large area requires many observations in many locations and then extrapolated to provide complete information about soil moisture content in the area. This method consumes time and costing.

There were many researches using remote sensing technology to estimate soil moisture. Remote sensing technology is suited to answer problem on the large area, including in soil moisture estimation. Research of remote sensing technology to assess soil moisture has been widely practiced, either through the use of optical imagery or images using microwave (RADAR image). Each technology has its own flaws and advantages. The use of RADAR imagery has advantages over optical imagery. One of them, the microwave character in RADAR is actively sent and received by the sensor, thus the use of it independent from the presence of sunlight. Beside of that, it can penetrate clouds. Ulaby et al. [1] used linear relationship approximation between surface measured soil moisture and radar signal for estimating soil moisture in an area. Dubois *et al* [2]

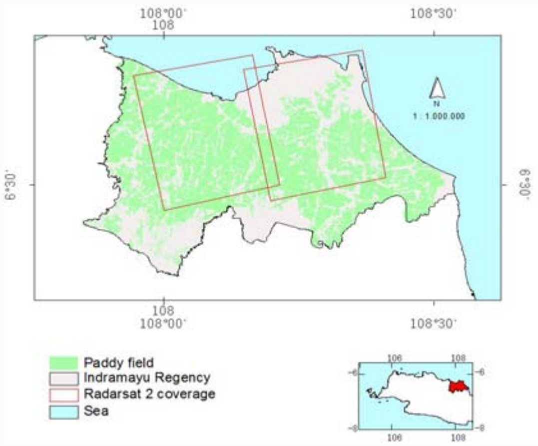


Figure 1: Map of RADARSAT 2 coverage in the Study Area.

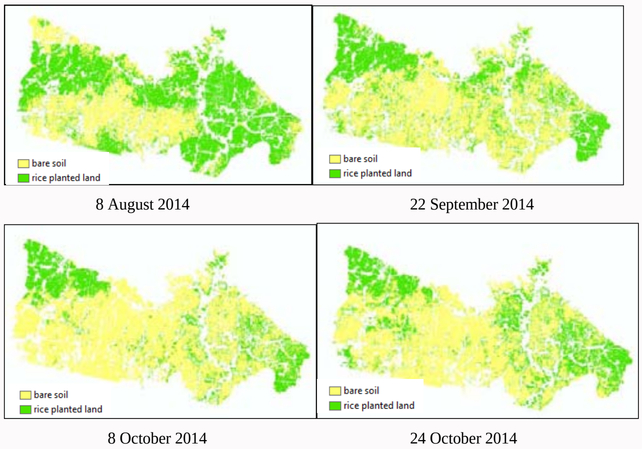


Figure 2: The distribution of bare soil and rice planted land in study area using NDVI approach.

developed a semi-empirical model to estimate moisture values and surface roughness by using RADAR imagery. That approximation is used and validated by other researchers [3] (Wang et al., 1997;). The Dubois semi-empirical model was developed using only one polarization (HH) of the two polarizations present in the image used (HH and VV). This kind of research was then followed by many other researchers [3-5] (Oh et al, 1992;). The models were then modified by other researchers to get more accurate results. Another model that used active microwave waves in estimating soil moisture and ground surface roughness was the Integral Equation Model (IEM) model [6,7]. The model had been also then widely adopted and modified by other researchers to get more accurate results, among other Song et al. [8] that using backscatter coefficient of soil multilayer in replace of soil surface, and Baghdadi *et al.* [9] had used 3 dimension input (HH, HV, and VV) in their network architecture (*Multi-layer perceptron (MLP) neural networks*) to estimate surface roughness and soil moisture. Both Dubois and IEM model were applied to vacant land (bare soil) or lands with rare closure.

This study describes the outcome of soil moisture estimation modeling on bare soil and rice planted land using high resolution RADARSAT 2 images.

Materials and Methods

Data and materials

Study area and time: The study was conducted on paddy fields in Indramayu district, West Java Province. Rice fields in Indramayu Regency are located in the North Coast of Java. western part of Indramayu is included in the Citarum watershed areas, while the eastern part is included in the Cimanuk watershed. At the time of the study, the irrigation pattern in the western part of Indramayu had been well developed where water coming from the Jatiluhur reservoir. Whereas in the East there is no water distribution from the dam, so most of the paddy fields are rainfed rice fields.

Soil moisture data were collected in the field with four times from August to October 2014. The timing of soil sampling in the field is adjusted to the RADARSAT 2 image acquisition schedule. Field observation and soil sampling are conducted in the dry season, with no rain falls conditions. At the time, the conditions of soil moisture condition and plant growth varied.

Data and materials: The main material used in this study are RADARSAT 2 imagery and soil moisture data. The RADARSAT 2 belongs to quad polarization that has four polarization bands (HH, HV, VH, VV) and high spatial resolution (4 meters). It use microwave with C-band to send signals.

Table 1: The dates of acquisition of RADARSAT 2 and Landsat 8 Imagery and their coverage.

No	RADARSAT 2		Landsat 8
	Acquisition time	Coverage area	Acquisition time
1	15-Aug-14	West Indramayu	21-Aug-14
2	22-Sep	East Indramayu	22-Sep-14
3	2-Oct-14	West Indramayu	8-Oct-14
4	16-Oct-14	East Indramayu	24-Oct-14

Table 2: The results of validity test to soil moisture estimation model in bare soil and rice planted land.

Band	Land Use Type	Equation	R^2	N	RMSE
VV	Bare soil	y = 0.0596x - 14.453	0.04	45	59.38%
	Rice planted land	y = -0.0417x - 11.246	0.05	27	83.66%
VH	Bare soil	y = 0.0662x - 23.698	0.04	45	59.67%
	Rice planted land	y = -0.0988x - 13.709	0.21	27	42.60%
HV	Bare soil	y = 0.0878x - 24.236	0.08	45	33.93%
	Rice planted land	y = -0.154x - 10.659	0.39	27	25.59%
HH	Bare soil	y = 0.1688 x – 17.881	0.25	45	25.06%
	Rice planted land	y = -0.1315x – 5.276	0.32	27	32.14%

The parameter of image data used to estimate soil moisture is the backscatter coefficient of each polarization. The imageries cover two different areas, that are the western and eastern part of the study area (Figure 1). Each of these coverage areas is acquired on two different dates. The properties of RADARSAT 2 image are presented in Table 1. Each area is acquired on two different dates.

In addition to the RADAR image, Landsat 8 images are used as supporting data to separate fallow land and spatially planted rice. The Landsat 8 images used are images that record the Indramayu region (path 121 raw 54) acquired near the acquisition dates of the RADAR Image used in modeling. Acquisition dates from the RADARSAT 2 and Landsat 8 imagery used along with the coverage area are presented in Table 1.

Soil moisture data is obtained through measurements of soil samples taken from the field. The unit of soil moisture is percent volumetric.

In addition to RADAR imagery, Landsat 8 imagery is used to separate fallow fields and rice planted fields spatially. The Landsat 8 images covered Indramayu region (path 121 raw 54) and they were acquired near the acquisition dates of the RADAR images. The acquisition dates of the RADARSAT 2 and Landsat 8 images with their coverage area are shown in Table 1.

The main equipment used to support soil observation and sampling is soil ring and Global Positioning System (GPS) devices. While the data processing equipment used to process data is Personal Computer (PC) with ArcGIS 10.3, NEST-5 and Excel software.

Method

Conceptual of research: This research was conducted in two different land cover types, bare soil and rice planted land. On bare soil, it is assumed that the backscatter value is a reflection soil surface properties through microwave medium. While on rice planted land, it is assumed that both plants and soils contribute incoherntly to the backscatter value of RADAR, which is accompanied by a two-way attenuation. According to Ulaby et al [10] the relationship between the total backscatter value (σ ° total), crop backscatter (σ ° crop), and soil backscatter (σ °soil)

On the land covered by the plant the equation is described as follows::

$$\sigma^\circ \text{ total} = \sigma^\circ \text{ crop} + \sigma^\circ \text{ soil} * \tau^2 \qquad (1)$$

Where: σ° total = total backscatter, σ° crop = crop backscatter, σ° soil = soil backscatter, and τ^2 = two-way attenuation

Bare Soil: Bare soil is land with fallow land land or land planted with small amounts of rice (rarely). Commonly bare soil in the field is paddy field that has been harvested and remained paddy stumps.

Identification of bare soil and rice planted land is done by the NDVI value approach of the optical image (Landsat 8). According to Dubois [2], there is a close relationship between the value of NDVI with the condition of cropping on a land. Land is considered fallow if the image has a value of NDVI <0.4. In this case, it will be considered to be planted with rice if the value of NDVI> 0.4.

In the fallow area the plant contribution to the total backscatter value is ignored so that the backscatter value is considered to be derived from the soil. Therefore the backscatter values are affected by the properties of the soil surface. According to Ulaby [11], soil moisture is an important factor that affects the value of SAR backscatter together with the roughness of ground surface.

Simple regression equation model between the backscatter values of polarizations (HH, HV, VH, VV) and measured soil moisture was used to estimate the soil moisture value in the bare soil. The model used linear regression equation. Thus the estimated value of soil moisture was retrieved by invertion to the built equation model. In general the relationship of this equation is described as follows:

$$\sigma^\circ_{\text{total}} = a.mv + b \qquad (2)$$

where: y = soil backscatter, mv = soil moisture, a and b = constanta value

Land planted with rice: According to Ulaby [10], on vegetated land the total value of backscatter is considered to be a contribution of soil and plant accompanied by two-way attenuation (eq. 1). The soil and plant (crop) backscatter are imaginary value that used in this model. The backscatter that retrieved by using equation model between soil moisture and backscatter coefficient in bare soil (eq. 2) was considered as soil backscatter. The attenuation factor is the plant factors that are considered to affect the backscattering of microwave that reach the surface of the earth. The attenuation factor in Ulaby model is determined by the properties plants such as stems, branches and twigs, as has been done by Wang and Qi [12]. In this study, the identification of plant parameter that influence to the attenuation factor was not conducted, but this factor could be calculated by the method that used by Srivastava et al. [13] in the field covered wheat. The presence of two way attenuation and plant backscatter are considered in this soil moisture estimation model as decribed in equation 1. Equation 1 was applied in rice planted land by substitution of soil backscatter model (eq, 2) in replace of soil moisture (mv) thus result the equation model as follow:

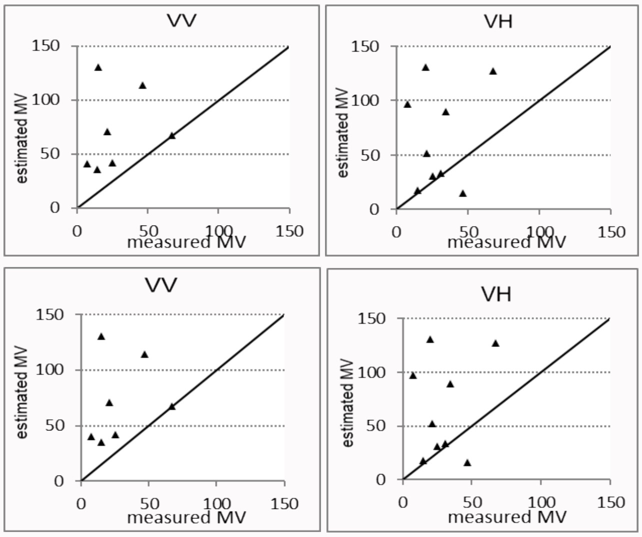


Figure 3: Scatter plot between measured and estimated soil moisture in bare soil.

$$\sigma^\circ_{\text{total}} = \sigma^\circ_{\text{crop}} + (a.mv + b) * \tau^2 \qquad (3)$$

Where: $\sigma^\circ_{\text{total}}$ = total backscatter, $\sigma^\circ_{\text{crop}}$ = crop backscatter, mv = soil moisture,

τ^2 = two-way attenuation, and a and b = constanta value in equation 2.

A new model equation was derived from equation 3 as linier equation model (y = ax + b) as follow:

$$\sigma^\circ_{\text{total}} = (\sigma^\circ_{\text{crop}} + b.\tau^2) + (\tau^2 a.mv) \qquad (4)$$

By expressing equation 4 as linear equation (Y = B + A*X), $\sigma^\circ_{\text{total}}$ was considered as independent variable (Y), mv as independent variable (X), $a.\tau^2$ as gradient constant (A), and ($\sigma^\circ_{\text{crop}} + b.\tau^2$) as constant (B). Then, the estimated soil moisture in rice planted land was retrieved by inversion to equation 4.

The crop backscatter ($\sigma^\circ_{\text{crop}}$) and two-way attenuation could be derived from the equation 4. Those factor could be calculated as follow:

$$\tau^2 = a/A$$

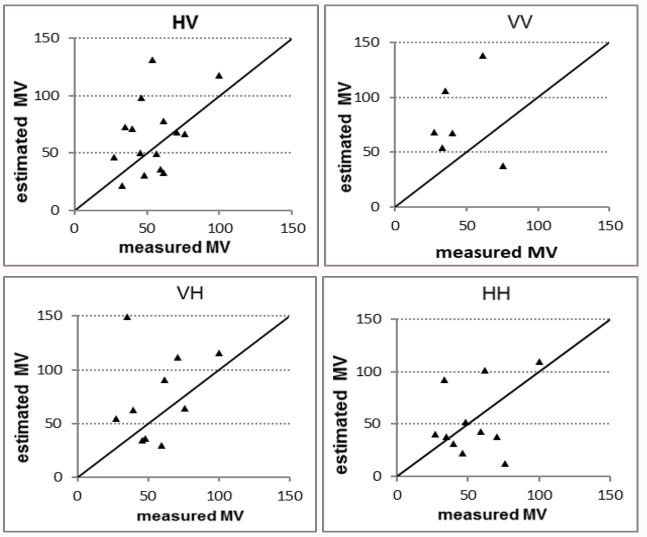


Figure 4: Scatter plot between measured and estimated soil moisture in rice planted land.

and

$\sigma^{o}_{crop} = B - (b^{*} a/A)$

Data collection

The timing of data retrieval in the field was adjusted to the times of RADARSAT 2 images acquisition that used in this study. The data are collected in the similar weather condition, in the dry season and no rain fall. The soil samples were collected from the surface of paddy fields by using ring, both in fallow condition (no rice planted) and rice land planted condition. Soil samples were taken to a depth of 5cm. Soil moisture was measured volumetrically from the sample soil rings after being dried in in laboratory. The number of samples taken as many as 94 observations, consist of 56 samples on fallow land (bare soil) and 38 samples on rice planted land. From the total data, 72 data sets were used as training data (45 in bare soil, 27 in rice fields), while as many as 22 sets were as test data (11 data for each type of rice field).

Extraction of image data: Radarsat 2 data that used on the soil moisture estimation model is backscatter coefficient. The used backscatter coefficient is located on site of soil sample for soil moisture analysis. The coeficcient are extracted from each band polarization (HH, HV,VH, VV) by using NEST program in decibel (dB) unit.

Regression analysis: Correlation between backscatter coefficient of each polarization and soil moisture is expressed by simple regression. On bare soil regression analysis is built between soil moisture and backscatter coefficient of each band directly (equation 2). On the rice planted soil, regression analysis is built with an assumption that totally backscatter coefficient is affected by soil and atanding crop above, and also affected by two way attenuation (equation 4).

Mapping: Spatialization of soil moisture is conducted by inverting the regression model between soil moisture and backscatter model. The inversion is applicated to the model under bare soil or rice planted soil. The map of soil moisture distribution is built by using ArcGIS 10.3 software with Raster Calculator menu. The results of soil moisture spatialization on the bare soil are combined with the result on rice planted land that has same acquisition time to retrieve the whole soil moisture condition of the paddy field at the same time.

Validation: This study used the indicator of determination coefficient (R^2) and *Root Mean Square Error* (RMSE) in measuring the accuracy of the models as suggested by Willmott [14], both in bare soil and rice planted land. R^2 was used to evaluate equation model between soil moisture and backscatter coefficient, whereas RMSE value was used by comparing the measured and the estimated soil moisture. As bigger as R^2 value, as better as the model, whereas smaller as RMSE value, as better as the model.

Results and Discussion

Distribution of bare soil and rice planted land

Based on the NDVI value approach, the paddy field area in Indramayu Regency is divided into fallow land (bare soil) and the land planted with rice as presented in Figure 2. Land is considered bare soil if the value of NDVI <0.4, while as the value of NDVI> 0.4 it will be considered to be planted with rice.

The green color shows the land planted with rice, while the yellow color shows bare soil.

The estimation model in bare soil

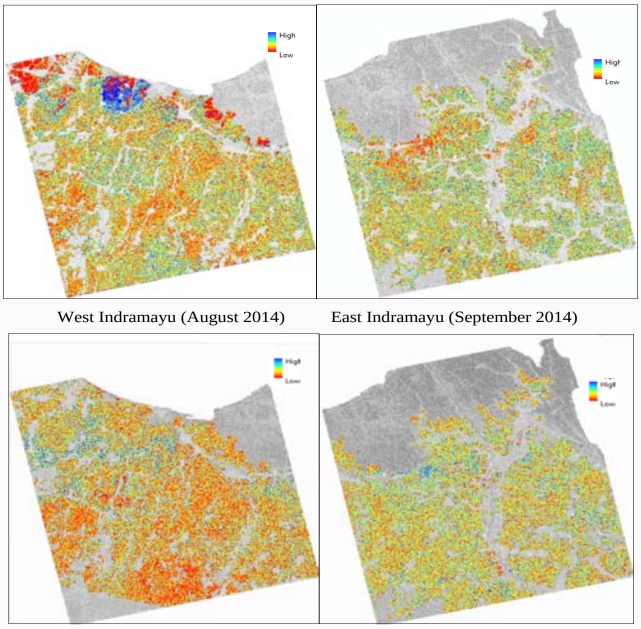
The estimated soil moisture was retrieved by inversion to the equation model between backscatter coefficients of polarizations (HH, HV, VH, and VV) and measured soil moisture values. This equation models and their determinant coefficient (R^2) are showed on the Table 2. Thus the estimated soil moisture values was compared with the measured soil moisture values.

The equation between the backscatters values and soil moistures commonly gave the low R^2 values, in range 0.03–0.221. The equation model using HH band has best result with the biggest R^2 value (0.22). The low determination coefficient explains that soil moisture is not the only factor that affects the backscatter value. There are other factors that give effect to the backscatter value simultaneously, whether from radar parameters or properties of ground surface object. Zribi et al [15] explained that there was the relationship between radar signal and incident angle, surface roughness, and soil moisture. The else is suggested that the presence of remained stumps with their variation in their biomass, density and height affect to backscatter value, thus it cause the low accuracy of the models. Beside of that, the difference RADARSAR 2 acquisition time between one each other is suggested has contribution to the low discrimination value, although the weather and environmental condition of observation area at the times are generally similar.

RMSE value shows how far the difference between the estimated soil moisture and the measured soil moisture value. RMSE value of the equation models are shown at Table 2. According to the RMSE values, commonly the accuracy of the models is low with the indication of the high RMSE value (25.06–59.4%). The equation model using HH band has best accuracy among all used band, with the lowest RMSE value (RMSE 25,06%). The figure show how far the difference between measured and estimated moisture of test data that predicted according the inversion of the linear equation of each polarization

Rice planted land

In rice planted land, backscatter values are principally affected by plants and soil surface properties. Simply the total backscatter value is the incorporation of the soil and crop backscatter value affected by the two-way attenuation. The total backscatter value is the backscatter value directly derived from the RADAR data, while



West Indramayu (August 2014) East Indramayu (September 2014)

West Indramayu (October 2014) East Indramayu (October 2014)

Figure 5: Soil moisture distribution on paddy field using HH band polarization in Indramayu.

the soil backscatter value is an imaginary value obtained through the equation model between the backscatter coefficient on the bare soil and the measured soil moisture (equation 2).

The crop backscatter (σ^o_{crop}) and the two-way attenuation coefficient (τ^2) are calculated as follow equation 4 and 5. the crop backscatter value of each polarization is -21.36, -49.08, -53.17, and -19.21 for VV, VH, HV, and HH respectively, while the two-way attenuation coefficient is -0.70, -1.49, 1.75, and 0.78 for each polarization respectively.

The values of crop backscatter (σ^o_{crop}) and the two-way attenuation coefficient (τ^2) are average of all observation in this research. These values are calculated on the assumption that the conditions of the rice plants are homogeneous. Calculation of crop backscatter and the two-way attenuation coefficient at every pixel is difficult. Theoretical model to calculate the crop backscatter and two-way attenuation coefficient required number of input parameters of the vegetation parameters and the radar parameters. The requirement make it impractical to use these models over large agricultural.

The results of simple regression equations between the backscatter coefficients of polarizations (HH, HV, VH, and VV) and measured soil moisture in rice planted land are presented in Table 2. The results show that the equation models between soil moisture and σ^o values have negative gradient value. This illustrates the tendency of the higher humidity, the backscattering values decrease. This is due to the very diverse conditions of soil moisture in the paddy fields, ranging from very dry to inundated conditions. Water in the soil is an element that affects the dielectric properties of the soil. Increasing soil water content to a certain level will increase the dielectric properties of the soil. Therefore an increase in soil water content tends to increase the backscattering values. The relationship of soil moisture to the dielectric properties has been widely investigated by previous researchers [16,17]. But waterlog soil have a different impact on the scattering value. The water body is like a mirror that has a smooth surface so that it reflects the coming wave forward. Therefore, stagnant water always gives a low backscattering value. This is what causes the equation gradient between soil moisture and the backscattering value in this paddy field is negative.

Generally these equation models have low determinant coefficient values (R^2 0.05-0.39), but this value is still better than the equation models in bare soil. The equation model that using band HV gives the best result with the highest determination coefficient (R^2 0.39), then followed by HH, VH and VV, respectively.

Estimation of soil moisture value in the study area is retrieved by inversion to the equation between the backscatter value and measured soil moisture, as has been done with the equation on bare soil. The estimated soil moisture is presented in the scatterplot paired with the measured soil moisture value (Figure 4).

Based on its RMSE value, the accuracy of estimation model in rice planted land is low with high RMSE value (Table 2). The equation model using the HV polarization in rice planted land gives the best result with the smallest RMSE value (25,59%). It is followed sequentially by HH, VH and VV.

The accuracy of soil moisture estimation is relatively low with low R^2 value and high RMSE value. Based on the validation test results, the HH and HV polarizations have almost the same validity. But overall, the HH polarization with 28.60% has better validity than HV average validity with 29.76%. This is presumably because many of the factors affecting the backscatter value are not used as input parameter in the estimation model. These parameters can be either parameters on objects on the earth's surface or radar parameters

Baghdadi *et al.* [18] in his study of soil moisture estimation on land dominated by corn and wheat, used the wavelength and roughness factor as input of the model. His study resulted models that had R^2 values with range from 0.13 to 0.71 and the best obtained RMSE values 3.74%. His models are applied to a certain range of angles. In another study, He *et al.* [19] used more detailed and complex plant property parameters as inputs in estimating soil moisture such as plant biomass, leaf surface area, plant height, plant water content, vegetation cover, plant density, physiological parameters and biochemical plants, leaf structure and spectral properties of plants. Their study produced the model with value $R^2 = 0.71$ and RMSE = 3.32%.

Spatially the estimated soil moisture distribution in the paddy field (in both bare soil or rice planted land) based on equation model using HH band polarization is showed in Figure 5.

Conclusion

The aim of this research is to find the best simple model to estimate soil moisture through high quad-polarimetric image of Radarsat 2 with conventional empirical linear approximation approach (y = a (x) + b) between radar signal (backscatter coefficient) and surface moisture. The equations are constructed between the backscatter coefficients of polarizations (HH, HV, VH and VV) and soil surface moisture, either fallow land (bare soil) or planted with rice. The estimated soil moisture values are then obtained through the inversion of the these equation models.

Generally linear regression equations between soil moisture and the backscatter values have a relatively low determination coefficient, with a range of R^2 values of 0.04-0.25 in bare soil and 0.05-0. 39 in rice planted land. Where as *Root Mean Square Error* (RMSE) of these models is relatively high with range 25,06 – 59,67% in bare soil and 30,92 – 83.66 in rice planted area. The presence of other factors that affect backscatter value and not considered as parameter input in the estimation model, either from properties of used microwave or ground surface object, is suggested contribute to the low R^2 value and the high RMSE. The equation model using the HH polarization in both bare soil and rice planted land gives the best result with the smallest average RMSE value (28,6%). It is followed sequentially by HV, VH and VV.

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