DEVELOPMENT OF LAND MOISTURE ESTIMATION MODEL USING MODIS INFRARED, THERMAL, AND EVI TO DETECT DROUGHT AT PADDY FIELD

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Abstract. The drought phenomena often occurs in summer season at paddy field of Java island. The drought phenomena causes decrease in rice production. This research was aimed to develop a model of land moisture (LM) estimation at agricultural field, especially for paddy field based on Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data which has seven reflectance and two thermal bands. The method used in this study included data correction, advance processing of MODIS data (land indices transformation), extraction of land indices value at location of field survey, and regression analysis to make the best model of land moisture estimation. The result showed that reflectance of 2^{nd} channel (NIR) and rasio of Enhanced Vegetation Index (EVI) with Land Surface Temperature (LST) had high correlation with surface soil moisture (% weight) at 0 – 20 cm depth with formula: LM = 15.9*EVI/LST – 0.934*R2 – 16.8 (SE=9.6%; R^2=76.2%). Based on the model, land moisture was derived spatially at the agricultural field, especially at paddy field to detect and monitor drought events. Information of land moisture can be used as an indicator to detect drought condition and early growing season of paddy crop.

Keywords: *MODIS, reflectances, EVI, LST, land moisture, paddy*

1 INTRODUCTION

Soil moisture condition is one of important variables for farmers to monitor and support crop growth in any stage. The soil moisture can be derived by direct or indirect measurement. The direct measurement of soil moisture is conducted through ground survey with equipments, such as the gravimetric technique and soil moisturemeter. The direct method can provide very accurate information, but spends a lot of budget in measuring a wide area. The indirect measurement of soil moisture can be made using the satellite remote sending technique. The satellite remote sensing data can cover a wide area at once and monitor the fluctuation of soil moisture condition using their temporal resolution capability. Therefore, the limitation in the conventional method to monitor soil moisture condition can be resolved using satellite remote sensing data.

Study of estimating soil moisture using satellite data were conducted by Takeuchi and Yasuoka (2004) and Wang (2005). The soil moisture estimation model was developed using Landsad Thematic Mapper (TM) and Moderate Resolution Imaging Spectroradiometer (MODIS) data, which both data were different in spatial and temporal resolution. Dirgahayu (1997) was derived soil moisture estimation from Soil Brightness Index (SBI) using Landsat TM in the plantation area of sugar cane in Jatitujuh, West Java. The principal component analysis of Landsat TM bands was used to estimate SBI. The correlation between SBI and soil moisture was high. However, Landsat ETM 7 data with 30 m spatial resolution has ability to cover at certain area and at certain time, and also has only of 16 days of temporal resolution. In addition, they have SLC off problem since June 2003. Meanwhile, Takeuchi and Yasuoka (2004), and Wang (2005) investigated that the indices of vegetation, soil, and water can be produced using MODIS near infrared, visible, and short wave infrared bands. Although MODIS has lower spatial resolution (250 m and 500 m) than Landsat

TM, MODIS can provide daily information of soil moisture.

Potential soil moisture also used for other applications, Iverson *et al*. (1997) used Geographic Information System (GIS) technique to combine elevation, soil moisture, and soil map to predict forest composition in Ohio forest. Other research Research also conducted to make soil moisture estimation model using combination parameter of EVI, LST, and NDWI extracted from MODIS (Hosseini and Saradjian, 2011).

The objective of this research was to estimate soil/land moisture condition in the agricultural land, especially in paddy field based on combination of visible-infrared bands, vegetation index, and land surface temperature from the MODIS data.

2 MATERIALS AND METHOD

2.1 Data

The daily MODIS reflectance data for the period of June-September 2004 and July -September 2005 were used in this study. The location of research was in Central Java and East Java. The field measurements of the surface soil moisture were obtained by doing field measurements (ground truth) in the study area at the same period with MODIS data acquisition time. The soil samples at paddy field were taken from 0-20 cm of soil depht from surface with various paddy crop condition. The soil samples from field measurement were analyzed at the Soil Physic Laboratory to measure water soil content using the gravimetric method (total 52 training samples). Location of field survey can be shown Figure 1.

2.2 Data Processing and Analysis

The corrected reflectance from the atmosphere effect in each channel of MODIS level IB data was produced by level 2 processing. Furthermore, some processed were conducted to improve and repair the data quality, such as: Bow-Tic correction and geometric correction to make the data in the same spatial resolution (250 m). The flowchart of data processing and analysis of this research can be shown in Figure 2.

Enhanced Vegetation Index (EVI) was calculated using blue, red, and NIR bands with formula as follows:

$$EVI=2.5*(\rho2-\rho1)/(1+\rho2+6*\rho1-7.5*\rho3)...(1)$$

where: ρ1, ρ2, ρ3 are red, near infra red

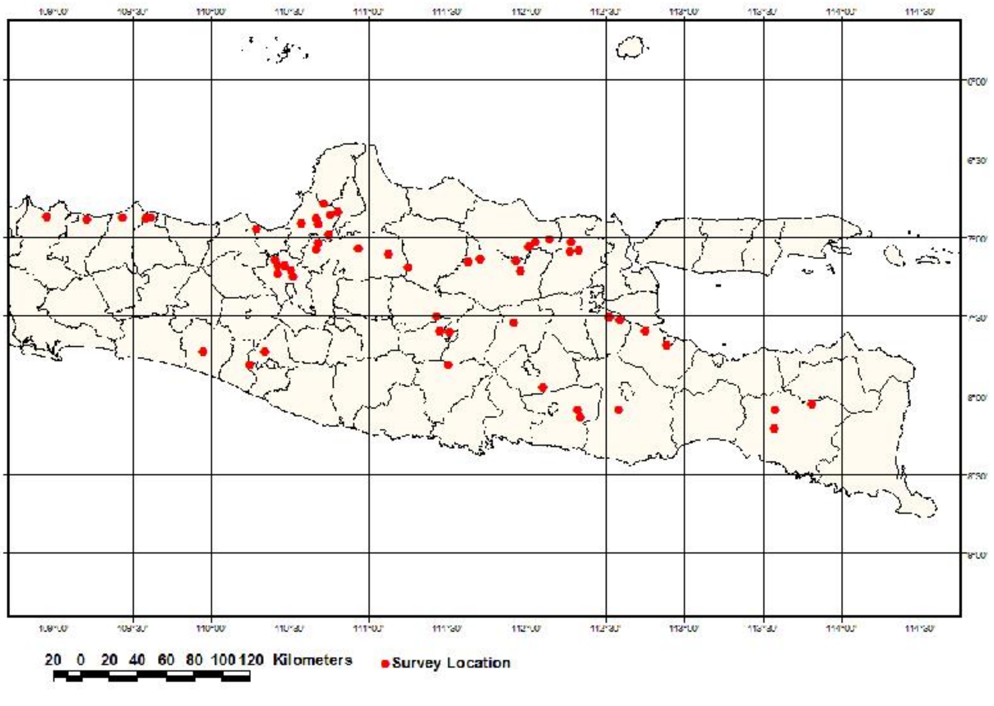

Figure 1. Distribution of paddy crop and soil sample at central and east Java.

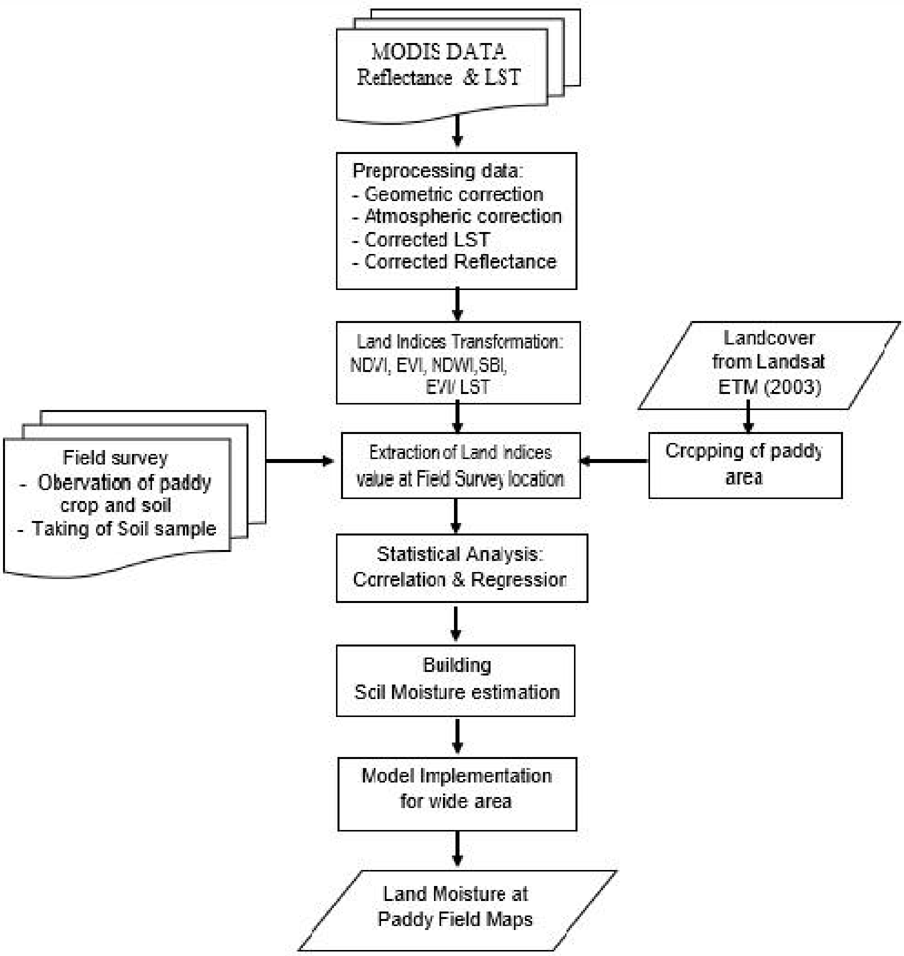

Figure 2. Flowchart of data processing and analyses.

(NIR), and blue band reflectances of MODIS data, respectively. On the other hand, Land Surface Temperature (LST) can be obtained directly from MOD11 (one of MODIS data products).

In the next step, statistical value of the minimum, maximum, mean, median and standard deviations for each reflectance band, EVI, and LST of MODIS data were calculated inside training sample made based on ground survey point by considering homogeneity of pixels. Training samples were taken using RGB 621image.

The correlation and regression analyses were performed to determine the correlationship between MODIS reflectance bands, EVI, LST and soil moisture. The surface soil moisture values used in correlation were less than 75% (based on dry weight in 0 – 20 cm of soil depth). Then, the Stepwise regression was applied to select 2 or 3 best variables for estimating surface soil moisture. The simulation model were conducted in non linear form (power, exponential, or logarithmic) for obtaining the best estimation model (the highest determination coefficient (R^2) and the smallest standard error (SE) (Morisson, 1990)).

3. RESULTS AND DISCUSSION

3.1 Spectral responses of MODIS reflectances

The value of MODIS reflectances (Rl to R7) and soil moisture data from the field measurement in central and east Java are shown in Table 1. The scatterplot between each MODIS reflectances (R1, R2, and R3) and the soil moisture are shown in Figure 3, 4, and 5.

Table 2. Mean reflectance of MODIS at each location, where soil sample intake during July - September 2004 and July-September 2005 in central and east Java.

No	R1	R2	R3	R4	R5	R6	R7	SM
1	28.2	39.3	22.0	25.8	46.1	40.6	28.7	4.6
2	18.7	31.4	15.0	16.6	30.8	24.5	15.5	10.2
3	10.7	18.7	11.6	11.6	21.2	18.4	11.6	12.4
4	12.8	21.5	10.1	10.7	21.7	21.1	14.7	14.1
5	12.4	27.9	7.8	10.0	26.8	21.8	12.6	24.7
6	9.8	20.1	10.2	10.4	22.2	19.7	12.0	27.6
7	8.9	20.9	8.2	9.1	22.3	19.0	11.2	31.9
8	7.9	26.7	8.7	9.3	25.1	19.5	11.5	33.5
9	9.9	28.5	5.1	9.3	32.4	28.6	16.7	33.9
10	10.0	29.0	9.7	11.8	30.7	22.9	13.3	34.2
11	7.9	25.7	8.7	9.2	24.0	17.6	9.5	35.9
12	11.3	33.4	8.1	11.3	32.6	25.1	15.1	36.6
13	10.1	32.2	6.9	10.6	35.5	28.0	16.2	36.6
14	9.0	22.5	7.2	9.2	18.8	16.4	9.2	37.9
15	9.2	24.4	6.7	9.0	22.1	20.1	10.8	43.0
16	13.7	25.1	6.4	10.9	31.6	31.2	21.9	44.0
17	3.8	14.5	2.2	4.8	20.2	14.7	8.0	47.4
18	8.7	32.9	4.6	8.9	34.4	28.1	17.1	48.9
19	7.4	24.2	8.2	8.7	24.2	16.3	7.9	49.4
20	11.2	23.9	5.9	9.9	26.0	23.9	16.1	49.6
21	6.2	24.8	4.1	8.0	29.4	20.8	11.8	50.9
22	9.8	28.7	8.5	10.5	36.5	19.4	10.4	52.0
23	6.6	18.1	4.6	8.6	26.0	22.9	14.3	52.0
24	8.3	22.1	6.2	9.1	22.1	18.0	10.2	52.9
25	5.7	30.9	3.0	7.5	28.6	18.9	8.8	57.1
26	7.4	28.7	2.9	7.0	25.3	17.4	9.1	57.9
27	6.9	28.2	3.6	7.1	26.3	19.6	11.5	58.7
28	10.9	20.7	9.7	13.9	23.7	20.5	13.2	59.0
29	5.2	38.9	2.9	7.6	35.1	22.0	10.7	60.1
30	6.5	25.1	5.7	7.4	21.9	14.5	8.3	61.4
31	39.2	46.7	28.1	31.8	41.5	35.8	24.9	62.1
32	7.7	27.7	8.0	9.6	32.9	24.2	11.3	62.4
33	12.7	26.5	9.6	13.7	33.5	28.7	18.9	66.5
34	6.5	25.7	7.3	7.8	21.1	15.4	8.5	66.7
35	5.9	34.7	3.4	7.8	29.8	19.9	10.0	66.7
36	5.2	26.1	3.1	6.9	23.5	16.1	7.1	67.0
37	6.9	21.0	3.4	6.8	16.8	12.9	7.2	67.5
38	25.5	36.7	10.7	12.0	20.4	17.1	11.0	69.3
39	8.3	24.8	4.2	7.6	55.2	22.4	15.0	71.1
40	5.3	35.7	5.9	7.5	29.0	18.4	7.9	72.8

Notes: R1-R7 Reflectances of red, NIR, blue, green, middle IR and MIR (middle infra red) in %; SM (Soil Moisture (gr water/dry soil) in %)

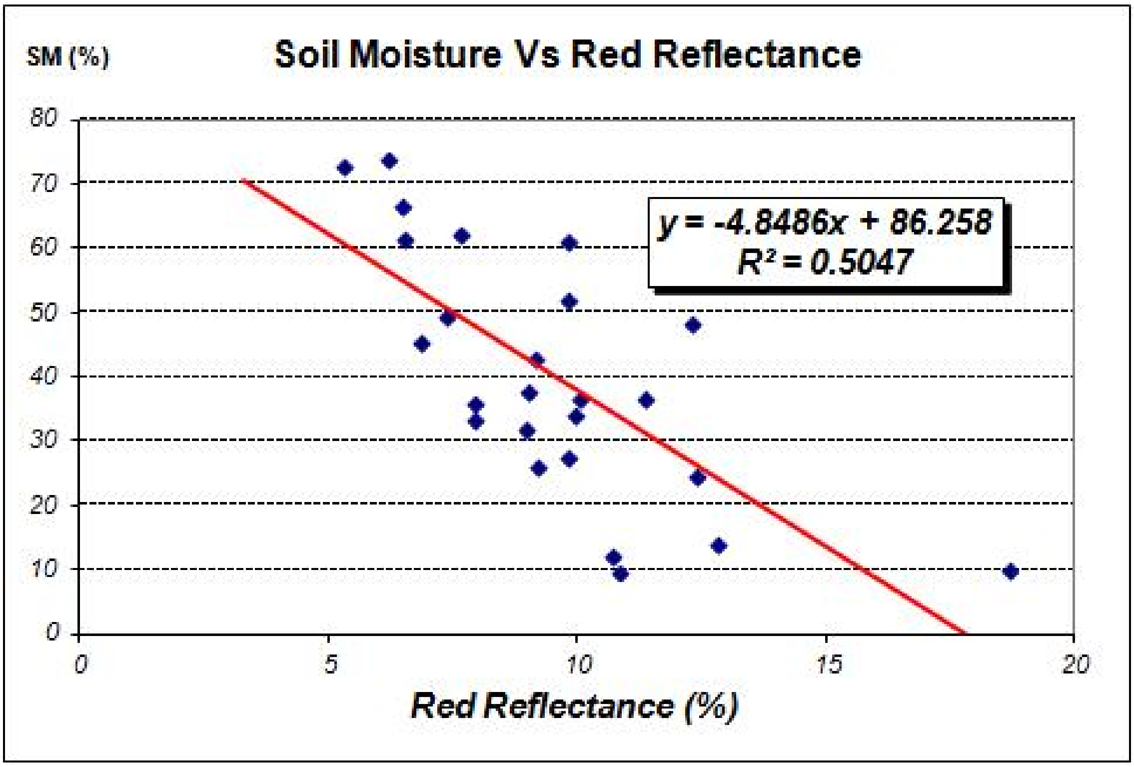

Figure 3. Correlation between red reflectance band (R1) of MODIS and soil moisture.

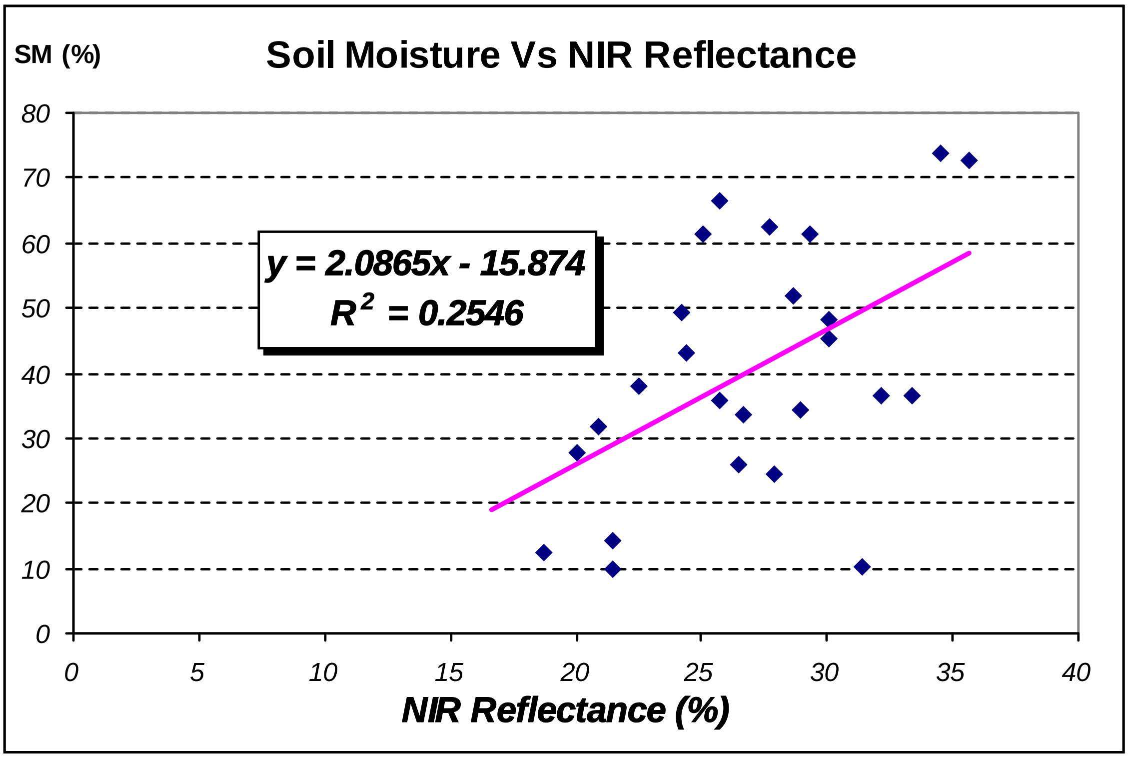

Figure 4. Correlation between NIR reflectance band (R2) of MODIS and soil moisture.

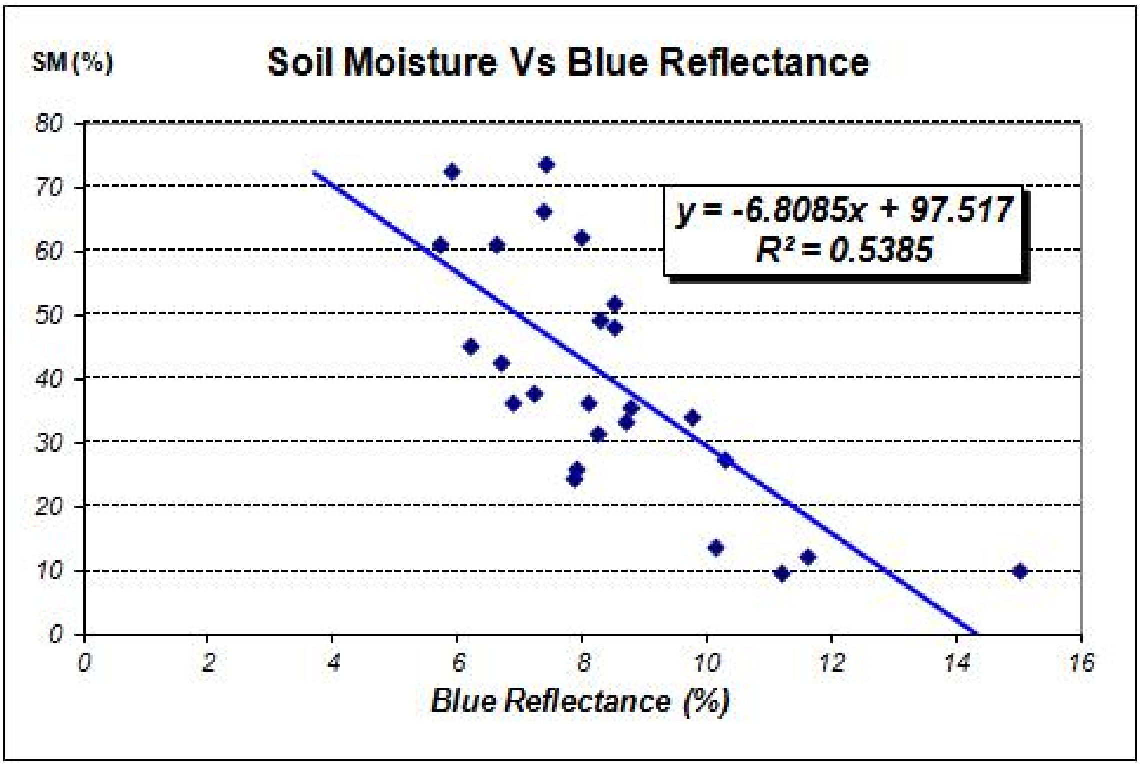

Figure 5. Correlation between blue reflectance band (R3) of MODIS and soil moisture.

Based on the results, the correlation between NIR reflectance and soil moisture had a positive correlation, while correlations between other reflectance bands (red and blue) had negative correlations. High spectral response in NIR band showed that the area (land) had vegetation with dense canopy. Therefore, a positive correlation between NIR band and soil moisture indicated that land with dense vegetation canopy had more water content comparing to land with less vegetation or bare land. NIR band can also be represented by vegetation index or EVI (Enhanced Vegetation Index).

The results from the regression analyses (include T-test and Probability) among all MODIS reflectance bands (R1 to R7), EVI, LST and other parameters, such as Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Soil Brightness Index (SBI) with soil moisture are presented in Table 2.

Furthermore, it can be selected two or three higher predictors based on the regression results in Table 4 or trough the Stepwise Regression Procedure. Two variables of predictor were selected based on the Stepwise Regression (Table 4) for land moisture (LM) estimation. The derived model (SE=9.61233, R^2=76.2%) was as follows:

$$LM = -16.8-0.934R2+15.9EVI/LST \quad ...... (2)$$

The generated model was then implemented to produce spatial distribution of soil moisture in paddy field with the scale up to the district level using MODIS data (Figure 5). Afterwards, the potential drought was predicted based on soil moisture information. The result showed that the drought condition in a paddy planting area had soil moisture no less than 25 %. On the other hand, the early growing season of paddy crop can be started when the paddy field had more than 25% of soil moisture.

Table 3. The regression analyses result among MODIS reflectances (R1 to R7), vegetation index (EVI, NDVI), LST (Ts) and soil moisture.

Predictor	Coef	SE Coef	T	P
Constant	-471.9	212.9	-2.22	0.036
R3	-5.556	7.76	-0.72	0.481
R4	3.669	3.481	1.05	0.302
R1	6.971	8.195	0.85	0.403
R2	-5.864	3.47	-1.69	0.103
R5	0.3245	0.6709	0.48	0.633
R6	-1.02	1.614	-0.63	0.533
R7	2.393	3.736	0.64	0.528
Ts	5.858	3.008	1.95	0.063
NDVI	784.9	418.9	1.87	0.073
EVI	-630.7	534.7	-1.18	0.249
EVI/Ts	210.5	110.2	1.91	0.068
NDVI/Ts	-147.74	89.54	-1.65	0.111
VI/Ts	-0.994	1.408	-0.71	0.487
NDWI	-77.26	77.01	-1	0.325
SBI	18.06	98.39	0.18	0.856

Table 4. The stepwise regression result to select 3 best predictors of variables to estimate soil moisture.

Predictor	Coef	SE Coef	T	P
Constant	-16.75	10.05	-1.67	0.104
R^2	-0.9343	0.3018	-3.10	0.004
EVI/Ts	15.865	1.439	11.02	0.000

Table 5. Analysis of variance.

Source	DF	SS	MS	F	P
Regression	2	11248.0	5624.0	60.87	0.000
Residual Error	38	3511.1	92.4		
Total	40	14759.1			

4 CONCLUSION

The model of soil/land moisture in the in paddy field was developed based on combination of visible-infrared bands, vegetation index, and land surface temperature from the MODIS data.

Combination of NIR Reflectance (R2), EVI and LST of MODIS data were the best parameters to estimate land moisture with the equation of LM = - 16.8 - 0.934 R2 + 15.9 EVI/LST (SE=9.61233, R^2=76.2%).

Land Moisture can be used as one indicator to detect of drought in the paddy field and early growing season of paddy crop. The drought condition in a paddy planting area had soil moisture no less than 25 %. On the other hand, the early growing season of paddy crop could be started when the paddy field had more than 25% of soil moisture.

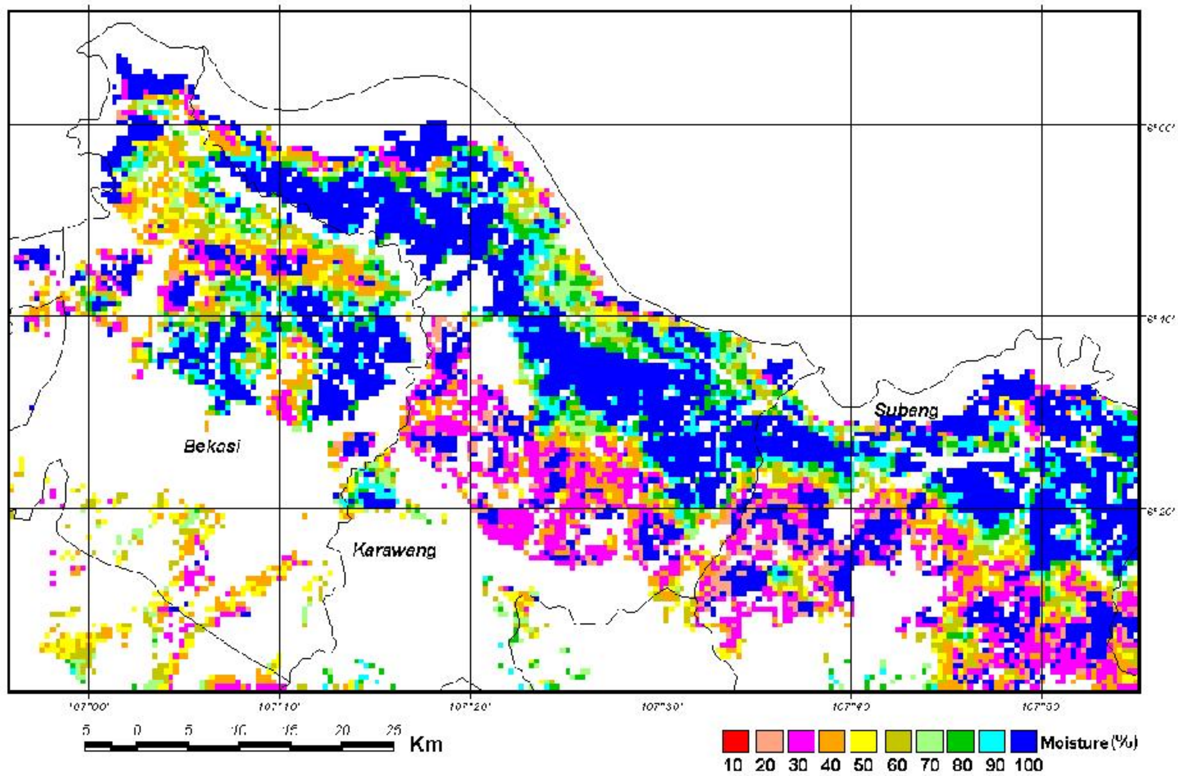

Figure 5. Spatial distribution of land moisture on the second week of August 2005 in west Java Province.

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