Integration Satellite Multi Resolution Image Data Using Wavelet Transform to Identify Soil Moisture Dynamics at Lampung Tengah, Indonesia

Dwi Rustam Kendarto[1]

[1]Padjadjaran University, Department of Agricultural Engineering,
Jl. Bandung-Sumedang Km 21, Bandung Indonesia
dkendarto@yahoo.com

Abstract: ***Soil moisture is important information in management efficiency water irrigation plantation with technical irrigation systems. One method of determining soil moisture, the use of remote sensing data is very beneficial because it can record soil moisture with fast time duration. But needs to be considered is how far the ability of remote sensing data to describe the distribution of soil moisture content. This study aims to determine the moisture content of soil using remote sensing data and imagery of the Land Satellite Thematic Mapper imagery (Landsat TM7) and MODIS (Moderate Resolution Imaging Spectroradiometer) and integrated model with wavelet transform. Determination of moisture content of soil used a triangle model of Carlsson and field data. The data field was done by measuring soil moisture content daily with a depth range of 10 cm to 100 cm depth. Wavelet transformation was used to integrated soil water content form landsat TM7 imagery analysis and MODIS image analysis to improved spatial resolution and temporal resolution. Location of the research done on pineapple plantations in Terbanggi Besar Lampung Tengah. The result showed that the remote sensing data was able to identify the moisture content of the soil especially for depth less than 40 cm. Absolute error for a depth of less than 40 cm are 7, 24 for Landsat and 5.84 for MODIS. Ability of soil moisture content determination from Landsat and MODIS imagery to increase the depth of the lower soil solum. The ability to image Landsat soil moisture content idenfikasi better at a depth of 10 cm to 40 cm instead of using MODIS. Root mean square error values for a depth of 10 cm was 2.2. For the Landsat TM7 and 2.44 for MODIS, the relative error of 13.15 for the Landsat and to 15.98 MODIS. Average absolute error Landsat images to a depth of 10 cm was 4.83 for Landsat and 5.95 for MODIS. Based analysis absolute error, root mean square and the relative error can be stated that the Landsat better in determining soil moisture compared to the MODIS imagery. Wavelet transform can improve spatial resolution and temporal resolution to follow the characteristics of temporal resolution and best spatial resolution of the input data.***

Keywords: Soil moisture content, remote sensing data, wavelets transform.

1. Introduction

Soil moisture information is one indicator of drought and is the basis of action provision of irrigation water for plants to live optimally. The amount of water supplied to be adjusted with needs water plants and water needs to fill the pores of the soil to field capacity. If the amount of water supplied exceeds field capacity, the water will be forwarded to the layer below it so it can not be used by plants. However, if the availability of soil moisture is less than the crop water requirement will cause a decrease in growth rate may even cause plant death if the condition has passed the point of permanent wilting.

Estimation of soil moisture can be done directly or indirectly. Estimation is directly done by measurement of the moisture content of soil samples taken in the field. This technique is quite accurate, but for a wide area and continuous improvement takes time and costs. Estimation of soil moisture can indirectly be done in two ways: the use of sensors that directly applied to the soil solum and use of sensors without the object, then converted to soil moisture values. Sensor application techniques in the soil solum less suitable for wide area and short duration. The use of the

Sensor without touching an object that can be widely assumed soil moisture with a very fast time is very suitable using remote sensing techniques.

Remote sensing techniques aimed at monitoring and modeling processes on the Earth's surface and its interaction with the atmosphere, measurement and assessment of geographically, biological and physical variables and identifying materials on land cover and signification spectral analysis required by satellites and aircraft sensors (Tuia and Camps-Valls, 2009). Problems were encountered in the actual reduction of dynamic information is usually the availability of reliable data are lacking. The need for data on soil moisture information on an agricultural land is the speed of information and detail data.

Remote sensing techniques as a technique of tapping the earth's surface condition information is able to record accurately the conditions of soil moisture in a large area. Approach to vegetation characteristics and air temperature to determine moisture content of the soil parameters because both parameters have a strong relationship with soil moisture content. One model estimates of soil moisture to do with the triangle model of distribution of surface temperature (Ts) and vegetation index (Carlson et al., 2007; Nishida, 2003). Things that needs to be known is how far the ability of remote sensing imagery is able to describe the distribution of spatial soil moisture content?

The purpose of this study is assessing the ability of the optical system of remote sensing data; Landsat TM7 and MODIS imagery in providing information on soil moisture content.

2. Material and Methods

The research was conducted at the pineapple plantation in Terbanggi Besar Lampung Tengah May Indonesia June to September 2011. The data used in this study the remote sensing image data Landsat TM7 Month in May through September 2011 were directly downloaded from the service provider Landsat TM7 online the pages of https://earthexplorer.usgs.gov/. While the MODIS imagery obtained from LAPAN (Lembaga Penerbangan dan Antariksa Nasional) with duration of eight daily. The study area is presented in Figure 1.

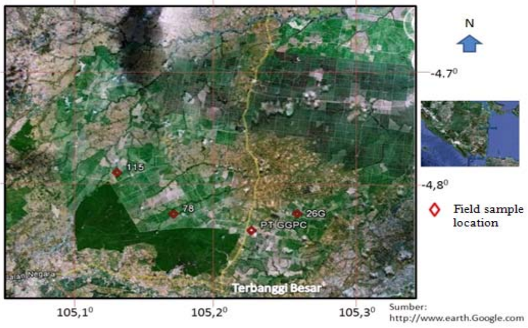

Figure 1. The Study area with daily soil moisture data location

Field data was result by measuring into the soil column using soil moisture measuring instrument with a probe length of 1 meter with a sensor mounted on a 10 cm depth ranges from 10 cm to 100 cm at three observation sites. Refers to the value of the sensor capacitance, value was sensor reading then converted to percent by volume. Observations made during the three months to obtain the value of the daily soil water content

Landsat and MODIS imagery was used in this study then the data field that has been done so it can be linked between field data and predictions from the image. The Landsat and MODIS imagery used is presented in Table 1.

Table 1. List Image was used in this research and time collect

Image	*Recording Time*	*Image*	*Recording Time*	*Number of scene*
MODIS	2-6- 2011	Landsat	25-7-2011	124/63
	10-6-2011		19-7-2011	124/63
	18-6-2011		4-9-2011	123/63
	4-7-2011		10-8-2011	124/63
	12-7-2011		26-8-2011	124/63
	5-8- 2011		6-9-2011	123/63
	13-8-2011		11-9-2011	124/63
	6-9-2011			

Soil moisture information can be done through a transformation, using the vegetation index and surface temperature. Vegetation index was used the NDVI (normalized deferential vegetation index). Furthermore, NDVI image and the image of the surface temperature is expressed in fractions of an index to form a range of values 0-1. Both of these data is combined with models of quadratic count Gilles, Carlson, 1997 (VI-ts triangle models) to get the value of soil moisture content. Vegetation index image is obtained by combining red channel (R) with the image of the channel infrared (IR) with the calculation formula:

$$NDVI = \frac{(R - IR)}{(R + IR)}$$

The surface temperature is obtained by image processing of thermal infrared (band 6 for Landsat TM7 and bands 31 and 32 for the MODIS imagery) into digital values by lowering the surface temperature values either using degrees Kelvin or Celsius depending on the needs of the equation. Determination of the surface temperature by the image processing followed the following equation:

Spectral radians (Lx) formula (USGS, 2002):

$$L_x = \left(\frac{L_{max} - L_{min}}{QCAL_{max} - QCAL_{min}}\right) x(QCAL_{max} - QCAL_{min}) + L_{min}$$

Temperature Brightness (Tb) formula (USGS, 2002):

$$T_b = \frac{K_2}{\ln\left(\frac{K1}{L\lambda} + 1\right)}$$

Surface temperature (Ts) formula (USGS, 2002)

$$Ts = \frac{Tb}{1 + \left(\frac{\lambda T}{\alpha}\right) \ln \varepsilon}$$

Soil moisture values was calculated by the triangular approach vegetation index and surface temperature data obtained from thermal infrared imagery. Determination of soil moisture (SM) using VI-Ts triangle models with equations (Carlson, 1995; Gilles, 1997; Carlson et al., 2007; Hossain 2008; Hong, 2008; Carlson, 2009):

$$SM = \sum_{i=0}^{i=2} \sum_{j=0}^{j=2} a_{ij} NDVI^{*(i)} Ts^{*(j)} \quad \text{and}$$

$$NDVI^* = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \quad \text{and}$$

$$Ts^* = \frac{Ts - Ts_{min}}{Ts_{max} - Ts_{min}}$$

with : *SM = soil moisture, NDVI = vegetation index, Ts = surface temperature*. Soil moisture formula from Carlson, 1994, became (Sharma, 2009):

$MV = a_{00} + a_{10}\, Ts^* + a_{20} Ts^{*2} + a_{01} NDVI^* + a_{02} NDVI^{*2} + a_{11} NDVI^* Ts^*$

with $a_{i,j}$, was constant value of polynomial function.

Polynomial constanta for formula carlston (Sharma, 2009):

constant	a_{00}	a_{10}	a_{20}	a_{01}	a_{02}	a_{11}
nilai	0.41281	-0.09738	0.04616	0.24222	-0.26776	-0.06243

Soil water content values was expressed in percent of the volume of soil water content, which can then be converted into ground water column thickness (mm) to fit the water balance calculations.

Wavelet transform use to combine landsat TM7 image analysis and MODIS image analysis to find spatial data like Landsat TM7 resolution and temporal data like MODIS temporal resolution.

The equation of wavelet tranformation makes two unit process; decomposition and reconstruction. Decomposition process result four image then that image was reconstruction to find image combined output. The decomposition equation are

$$c^{j}_{m,n} = \frac{1}{2}\sum_{k,l\in Z} c^{j+1}_{k,l} h_{k-2m} h_{l-2n}$$
$$d^{j1}_{m,n} = \frac{1}{2}\sum_{k,l\in Z} c^{j+1}_{k,l} h_{k-2m} g_{l-2n}$$
$$d^{j2}_{m,n} = \frac{1}{2}\sum_{k,l\in Z} c^{j+1}_{k,l} g_{k-2m} h_{l-2n}$$
$$d^{j3}_{m,n} = \frac{1}{2}\sum_{k,l\in Z} c^{j+1}_{k,l} g_{k-2m} g_{l-2n}$$

then reconstruction equation is;

$$c^{j+1}_{m,n} = \frac{1}{2}\left(\sum_{k,k\in Z} c^{j}_{k,l}\, \tilde{h}_{2k-m}\tilde{h}_{2l-n} + \sum_{k,k\in Z} d^{j1}_{k,l}\, \tilde{h}_{2k-m}\tilde{g}_{2l-n} + \sum_{k,k\in Z} d^{j2}_{k,l}\, \tilde{g}_{2k-m}\tilde{h}_{2l-n} + \sum_{k,k\in Z} d^{j3}_{k,l}\, \tilde{g}_{2k-m}\tilde{g}_{2l-n}\right).$$

Analysis of reliability and data verification of remote sensing techniques for the determination of soil moisture content determination performed using analysis of absolute error, relative error and root mean square error by comparing the predicted results and the data field data. The equation to determine the level of accuracy soil moisture from remote sensing data used root mean square formula that soil moisture data from image processing as predictor then soil moisture from field data as data observation. Absolute error and error values relative to the observational data used to performance test of image analysis are used with the equation: absolute error: $\sigma = \frac{1}{n}\sum_{i=1}^{n}(SM_{Prediction} - SM_{Observation})$,
relative error: $\sigma_r = \left(\frac{SM_{Prediction} - SM_{Observation}}{SM_{Observation}}\right) x100\,\%$

3. Result and Discussion

Determination of soil water content is obtained from the decrease image vegetation index (NDVI) and surface temperature image. Both images are used as input in the assessment of soil moisture content by using the equation developed by Carlson (1994). The equation uses the concept model of the reflection triangle curve between moisture content of the soil, vegetation index and surface temperature.

NDVI image shows vegetation density value, high NDVI values indicate high levels of vegetation density, low NDVI values values low vegetation density. Vegetation index is used as a basis for determining the moisture content of the soil vegetation index has a positive relationship with kandunngan soil moisture, so that the greater the vegetation index showed higher soil moisture values.

Surface temperature derived from thermal channels available in the Landsat and MODIS image. Landsat thermal infrared channels are channel 6 and channel MODIS thermal infrared imagery for the channel 31 and channel 32. Surface temperature values are expressed in degrees Kelvin or Celsius tailored to the needs, in this study the value expressed in Kelvin.

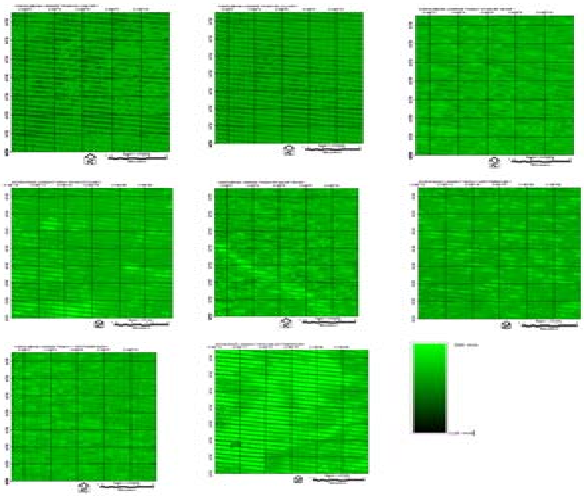

Figure 2. Soil moisture spatial distribution map form analysis Landsat TM imagery

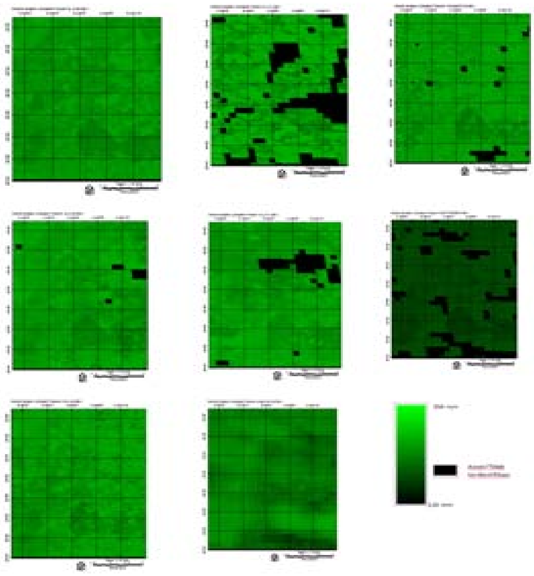

Figure 3. Soil Moisture from image processing of MODIS imagery

Distribution of soil moisture content results showed that at the beginning of September is the condition of the value of the lowest soil moisture content compared to the months of June and July. This is in accordance with data showing that rainfall in August was the lowest monthly rainfall at the site so the impact assessment in early September (source: Monthly rainfall PT. Great Giant Pineapple 1972-2010).

Soil moisture dynamics

The results of daily measurements of soil moisture in June - The month of September of the locations are presented in Figure 4.

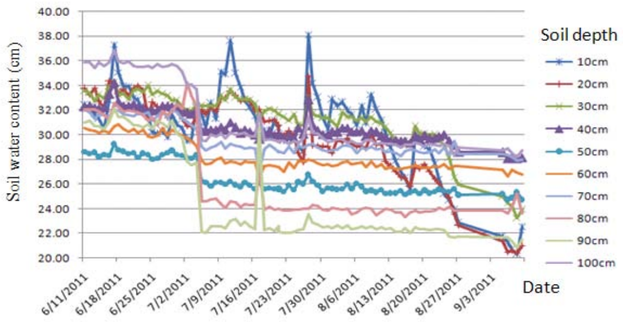

Figure 4. Result of measurement daily soil moisture at June to September

Based on the graphic of soil moisture content, it can be seen that at a depth of 10 cm to 40 cm soil water content fluctuations greater than the depth of the soil solum below. This indicates that the depth of 0-40 soil water content is strongly influenced by the dynamics of the land surface. The calculations show that kedalamaan 10 cm to 40 cm are affected by atmospheric conditions and environments so that changes in the land surface soil moisture content more dynamic.

The ability of Landsat TM7 and MODIS imagery for the determination of the soil moisture

The study was covered two Landsat scene the image of line 63 to column 124 and 123. The two images are different dates and therefore reliability analysis of remote sensing data for the identification of soil water content using the same field data recording time. Landsat TM7 addition, this study also uses MODIS images were recorded during the 8 daily, so getting a longer image data.

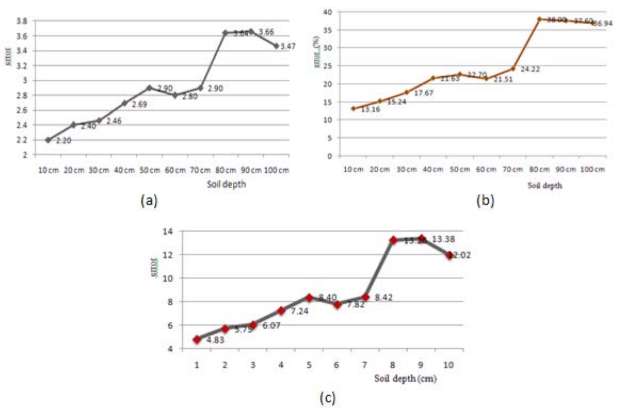

Figure 5. *Root mean square error* (a), relative error (b) and absolute error (c) soil moisture from Landsat TM image processing with field data.

These results suggest that Landsat TM7 well in describing the distribution of surface soil moisture, especially land. RMSE values of soil moisture content decreased image field with results indicate that at depths less than 50 cm error/standard deviation showed a considerable difference in the value. This is because at a depth of less than 50 cm the effect of capillarity of plant and the atmospheric dynamics affect the condition of the soil water content (Figure 5). The results of the calculation of the relative error per depth indicates that the deeper soil column Landsat lower ability to increase the value of the relative error (Figure 5). Lowest value of the relative error on kedalaman10 cm with relative error by 13.15% and increased the depth of the soil solum. The results of the analysis of the absolute error between the predicted moisture content of the soil results from Landsat TM7 and a depth of field measurement results show that the level of accuracy in soil columns Landsat TM7 lower (Figure 5). This is consistent with the nature of the electromagnetic waves used by the Landsat TM7. Landsat image using optical waves with the ability to penetrate to the lower soil column. The average absolute error

The results of the calculation of root mean square error indicates that the value of the error tends to increase in accordance with increasing depth of solum soil. Root mean square error value at a depth of 10 cm at 2.44, but at a depth of 30 cm and 40 cm decreased errors, but in general have a tendency to increase. The results of the calculation of the absolute error and relative error shows that the deeper the soil solum sensed, MODIS imagery more difficult to detect the moisture content of the soil conditions. It is shown that the deeper the depth of the soil solum increases tendency according to the level of absolute error and relative error (Figure 6)

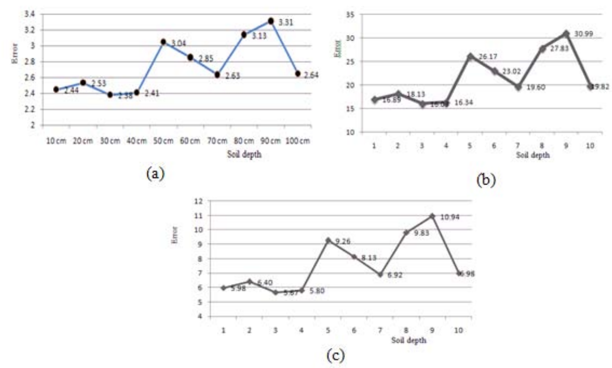

Figure 6. Root mean square error (a), relative error (b) dan absolute error (c) soil moisture condition between prediction from MODIS and from observe data per soil deep

The results of the analysis of root mean square error, absolute error and relative error for soil moisture loss data results Landsat and MODIS showed that the soil moisture content of the data processing results Landsat and MODIS has the tendency to decrease the level of ability in line with the increase in depth of soil solum dindera. Although there are several points that are smaller than the previous data, but in general forming lines increased (Table 2).

Table 2. Root mean square error, absolute error and relative error landsat satellite image and MODIS image about determination soil moisture of soil solum depth

Analysis	*Image*	*Depth of soil solum (cm)*									
		10	*20*	*30*	*40*	*50*	*60*	*70*	*80*	*90*	*100*
Root mean square error	Landsat	2,20	2,40	2,46	2,69	2,90	2,80	2,90	3,64	3,66	3,47
	MODIS	2,44	2,53	2,38	2,41	3.04	2,85	2,63	3,13	3,31	2,64
Absolute error	Landsat	4,83	5,57	6,07	7,24	8,40	7,82	8,42	13,20	13,38	12,02
	MODIS	5,98	6,40	5,67	5,80	9,26	8,13	6,92	9,83	10,94	6,98
Relative error	Landsat	13,16	15,24	17,67	21,63	22,70	21,51	24,22	38,00	37,60	36,94
	MODIS	16,89	18,13	16,03	16,34	26,17	23,02	19,60	27,83	30,99	19,82

Source: data analysis

The results of the analysis of root mean square error, absolute error and relative error generally indicates that the Landsat better at showing the distribution of soil kelengas with a pretty good degree of accuracy. The calculations show that the value Ladsat errors tend to be smaller than the value of the error MODIS. Besides the patterns formed closer to the average value line.

The results of the analysis of Landsat and MODIS imagery shows that the optical images for the condition of the ground water in drought conditions, the use of Landsat and MODIS imagery is still quite possible for irrigation is only done during the dry season. But the image of the optic has limited ability to estimate the moisture content of the soil at depths greater than 20 cm. However, this image can already be used as a tool for assessing the condition of the soil moisture content due to changes in the surface is associated with changes in soil moisture underneath. Using Landsat and MODIS will be useful for mapping the water shortage for low rooting depth of plants or plants that are sensitive to changes in soil moisture.

Table 2. Absolute error, relative error and RMSE analysis Landsat TM7 imagery, MODIS imagery and wavelet transform

Analysis	*Landsat*	*MODIS*	*Wavelet*
RMSE	2,2	2.44	2.93
Absolute error	13.6	16.89	10.2
Relative error	4.83	5.98	4.28

The results of the determination of moisture content of the soil analysis results Landsat and MODIS image analysis independently compared after penggabuan soil moisture content of the data from both image analysis shows that the absolute error and relative error of soil moisture content of the data results wavelet transform is smaller than the value of MODIS data errors , but larger than the error analysis of Landsat TM7. While the RMSE value data of the wavelet transform has a value greater than the value of RMSE data from Landsat TM7 and MODIS imagery analysis. This indicates that the wavelet transform shown the ability to enhance the temporal resolution of Landsat TM7 and improve the spatial resolution of MODIS imagery.

4. Conclusion

The determination of soil moisture through Landsat and MODIS images processing have the accuracy rate decreases with the increase into the soil solum. Solum depth of 10 cm has a value of absolute error, relative error and root mean square error lower than solum depth underneath. Absolute error at a depth of 10 cm is 4.83 for Landsat and 5.98 for MODIS imagery. Relative error of Landsat TM7 is 13.15 while 16.89 for MODIS imagery, the value of root mean square error for Landsat TM7 2.20 and 2.44 for image MODIS.

Based on the comparison of the absolute error, relative error and root mean square errors indicate that the ability of Landsat TM7 for the determination of soil moisture content is higher/ better than the MODIS imagery.

The use of wavelet transform mump improve the quality of data that is able to describe the distribution of soil moisture content more thoroughly with a higher spatial resolution and temporal resolution.

References

[1] Carlson, T.N., R. R. Gillis b., Thomas J. Schmugge. 1995. An interpretation of methodologies for indirect measurement of soil water content, Agricultural and Forest Meteorology 77 (1995) 191-205

[2] Carlson, T.N. 2007. An overview of the 'triangle method' for estimating surface evapotranspiration and soil moisture from satellite imagery, Sensor vol 4. p 1612-1629. www. Mdpi.org/sensor.

[3] Gillies, R.R., T.N. Carlson, W.P. Kustas, K.S. Humes. A verification of the `triangle' method for obtaining surface soil water content and energy fluxes from remote measurements of the Normalized DiVerence Vegetation Index (NDVI) and surface radiant temperature. int. j. remote sensing, 1997, vol. 18, no. 15, 3145 3166

[4] Ji, X., E. Kang., R. Chen, W. Zhao, Z. Zhang, B. Jin, 2007. A Mathematical model for simulation water balance in cropped sandy soil with conventional flood irrigation applied, Agricultural Water Management, 87 p 337-346. www.elsevier.com [download: 4 April 2011]

[5] [Keur, P., S. Hansen, K. Schelde, A. Thomsen, 2001. Modification of DAISY SVAT model for potential use of remote sensed data. Agricultural and Forest Meteorology 106 p 215-231. www.elsivier.com. [download:20 June 2011]

[6] Kovar, K., H.P.Nachtnebel, 1993. Application of information system in hydrology and water resources

management. Proceeding of an International Conference held ini Vienna, Austria, The International Commission on Groundwater of the International Association of Hydrological sciences (IAHS), IAHS Publication no 235.

[7] Koudmani, M., 2004. Application of remote sensing to hydrology and hydrology, International conf. on Water Resources and Arid Environment, http://www.psipw.org/English_PDF/3_Distance/E3-1.pdf [download: 20 Jun2 2011]

[8] Liang, S., 2004, Quantitative Remote Sensing of Land Surfaces, John Wilcy & Sons, Inc.

[9] Merlin, O., A. Al Bitar, J.P. Walker, Y. Kerr, 2009. A Sequential model for disaggregating near-surface soil moisture observations using multi-resolution thermal sensors, Remote Sensing of Environment 133, page 2275-2284. www.elsevier.com [download:4 April 2012]

[10] Moran, S. M., S. McElroy, Joseph, M. Watts, dan Christa D., Peters-Ledard, 2005. chapter 7: Radar Remote Sensing For Estimating Of Surface Soil Moisture At The Watershed Scale, texas. http://www.tuscon.ars.ag.gov/unit/publication/PDf files/1566.pdf.[download: 14 May 2011]

[11] Nasa (National Aeronautics and Space Administration),----, Specification, MODIS Web, http://modis.gsfc.nasa.gov/MODIS Website - Components of MODIS.htm.

[12] Nishida, K., Ramakrishna R. N., Joseph M.G., dan Steven W.R., 2003. Development of an evapotranspiration index from aqua/MODIS for monitoring surface moisture status. IEEE Transaction on Geosciences and Remote Sensing vol. 41 no. 2. p. 493-501.

[13] Petropoulus, G. T.N. Carlson. M.J. Wooter. S. Islam. 2009. A review of Ts/VI remote sensing based methods for the retrieval of land surface energy fluxes and soil surface moisture. Progress in Physical Geography 33(2) (2009) pp. 224–250

[14] Paniconi, A., Veroest, dan P.A. Troch, ---, Soil Moisture Mapping From Multitemporal Analysis Of Ers Sar Images, http://earth.esa.int/workshoper/ers97/papers/veroest/ [download: 19 November 2010] .

[15] Sudduth, K.A., C.W. Fraisse, S.T. Drummond, N.R. Kitchen, 1998. Integrating spatial data collection modeling and analysis for precision agriculture. International Conference on Geospatial Information in Agriculture and Forestry, Lake Buena Vista, Florida 1-3 June 1998.

[16] Tuia, D. dan G. Camps-Valls, Recent advances in remote sensing image processing Http://Www.Uv.Es/Gcamps/Conf/Icip09_Review.Pdf [2 October 2011]

[17] USGS, 2002, Landsat 7 Science Data Users Handbook, http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_htmls/chapter111.html.[download: 8 May 2011].

Author Profile

Dwi Rustam Kendarto, student at post graduate program in Agricultural Engineering, Bogor Agricultural University, Bogor, Indonesia, Lecturer in Department of Agricultural Engineering, Padjadjaran University, Bandung, Indonesia.