Land Moisture Estimation at Agricultural Land Using MODIS Data Based on NDSI, NDVI, and NDWI Indices

Dede Dirgahayu Domiri

Natural Resources and Environmental Monitoring Division
Remote Sensing Application and Technology Development Center
National Institute of Aeronautics and Space of Indonesia (LAPAN)
Phone/Fax: 62-21-8710274 / 8722733
e-mail: dede_dirgahayu03@yahoo.com

Abstract
This research is aimed to estimate land moisture condition at agricultural land, especially for paddy field based on MODIS (Moderate Resolution Imaging Spectroradiometer) satellite data with 250 m and 500 m spatial resolution and daily temporal resolution. An index is called Land Moisture Index (LMI) was created from 1st principle component result of NDSI (Normalize Difference Soil Index), NDVI (Normalize Difference Vegetation Index), and NDWI (Normalize Difference Water Index) with equation:

\[ LMI = 0.484 \times \text{NDSI} + 0.687 \times \text{NDVI} + 0.542 \times \text{NDWI} \]

There is a high correlation between LMI and soil moisture (LM) for the agricultural land with soil moisture \( \leq 75 \% \), whereas an increase of LM followed by an increase LMI. Finally, an estimation model has been developed to estimate land moisture condition for the agricultural land with equation:

\[ LM = 172.2145 \times \exp(-0.76102/IKL) \quad r^2 = 0.83 \]

Based on the above method, land moisture can be derived spatially for the agricultural land, especially for paddy field for drought prediction.

Keywords: land moisture, MODIS, linear combination, Land Moisture Index, surface soil moisture

I. INTRODUCTION

Available soil water is one of factors which is necessary for food crop agriculture, horticulture, plantation, and the forestry. Land moisture information is very needed for planning, monitoring, and management of agriculture crop. Soil moisture measurement through ground survey with conventional equipments like gravimetric, tensiometer, neutron probe can give very accurate information but needed expense costly for the very wide regional measurement.

Land moisture estimation by using Landsat Thematic Mapper (TM) have been conducted by Dirgahayu (1997) for the area plantation of sugar cane in Jatitujuh, West Java. Soil Brightness Index (SBI) was created by applying the principal component analysis onto band 2nd – 5th of Landsat TM. SBI could be used to estimate land moisture with high correlation. But Landsat TM data which have 30 m spatial resolution only according to be used at certain area and also for the certain time because this satellite own temporal resolution 16 days and now still have problem (SLC off). Meanwhile, information about land moisture oftentimes required for monitoring continuously, because early information about drought very needed to anticipate raisen impact.

One of exciting way to monitor land moisture at wide area every day is exploited satellite data such as MODIS data which own moderate resolution and the daily observation. Using Satellite Data can be decreased of costly expense.

In this research, the predictor parameter of land moisture derived from combination of modis reflectance which represented by NDWI (Normalize Difference Water Index), NDSI (Normalize Difference Soil Index), and NDVI (Normalize Difference Vegetation Index) and. Those Land Index have contrast given onto 3 general object on the earth such as water, soil, and vegetation. The objective of research is to develop the estimation model of land moisture by using land moisture index which derived from combination of 3 indices (NDSI, NDVI, and NDWI).
II. METHODOLOGY

2.1. Data Used
Data used for estimating land moisture are reflectances which derived from daily MODIS data on June, July, and August 2004 with the same time of ground survey to measure land moisture.

2.2. Field Data Processing
Soil sample which taken from field survey have analyzed at soil physic laboratorium by using gravimetric method. Afterwards, land moisture information can be known.

2.3. MODIS Data Processing

2.3.1. Corrected Reflectance
The corrected reflectance from atmosphere effect each channels of MODIS L1B Data produced by level 2 processing. Furthermore are conducted advance processing to improve and repair data quality, ie : Bow-Tie and Geometric Correction to make reflectances data in 250 m (R1, R2) and 500 m (R3 - R7) spatial resolution.

2.3.2. Making Indices
Three indices that can represent land condition (wet, dry, bare or vegetated) are NDWI, NDSI, and NDVI. Those indices are influenced by land moisture condition on surface (0 – 20 cm soil depth). Like as NDVI, NDSI and NDWI can be derived based on peak value of spectral response onto general objects (water, soil, vegetation) at wavelength variety which can be shown on Figure 2-1.

![General Spectral Response of Water, Bare Soil, and Vegetation at Variety Wavelength Spectrum](image)

Figure 2-1. General Spectral Response of Water, Bare Soil, and Vegetation at Variety Wavelength Spectrum

Peak values for vegetation object is shown contrastly at wavelength 0.6 μm (red) and 0.8 μm (near infra red). Peak values for water object is shown contrastly at wavelength 0.4 μm (blue) or 0.8 μm and 0.6 μm, while peak values of open area or bare soil lies at 0.8 μm and 1.8 μm (SWIR = short wave infra red). Research result by Dirgahayu (2005) obtain the best of 3 reflectances of MODIS data for estimating land moisture. Those are Red (R1), NIR (R2), and SWIR (R6) reflectances. Based on that result, so NDWI and NDSI can be created like as computing NDVI by using the following formula below

(a) \[ \text{NDWI} = \frac{(R1 - R6)}{(R1 + R6)} \] (2-1)

(b) \[ \text{NDSI} = \frac{(R6 - R2)}{(R2 + R6)} \] (2-2)

(c) \[ \text{NDVI} = \frac{(R1 - R6)}{(R1 + R6)} \] (2-3)
\[
\text{NDVI} = \frac{\text{NIR} - \text{Red}}{\text{Red} + \text{NIR}}
\]  
(2-3)

2.2.3. Analysis

Statistic value extraction (minimum, maximum, mean, median and standard deviation) for each reflectance of MODIS data was done in training area of ground survey point under homogeneity consideration. Training sample must be considered to composite RGB 6,2,1 image. Correlation and regression analysis was done to know relation among indices and land moisture, especially which have moisture less than 75 %. Principle component transformation will be conducted if there are significant correlations among indices. The result of the first principle component analysis will be used to create a new index hereinafter referred to as Land Moisture Index (LMI)

\[
\text{LMI} = b_1\times X_1 + b_2\times X_2 + b_3\times X_3
\]  
(2-4)

Where : \(X_1, X_2, \) and \(X_3\) are NDSI, NDVI, NDWI and \(b_1, b_2, b_3\) are vector eigen coefficients

For obtaining the best estimation model is conducted model simulation in non liner form (power, exponential, or logarithmic) between LMI and land moisture. The model selected is have high Determination coefficient \((R^2)\) and the smallest of standard error \((Se)\).

III. RESULT AND DISCUSSION

3.1. The Relationship between Land Indices and Land Moisture

To see relation among each index with land moisture, hence some locations have selected which have < 75 % moisture level. This is conducted because agricultural land with > 75 % moisture is relative more peaceful from drought risk onto crop growth. Extraction result of three indices and land moisture are shown in Table 1. The scatter plot between land moisture and each index and also result of trend analysis are shown in Figure 1 until Figure 5.

Table 3-1. Example of Mean Indices Value Extraction Result at Sample Location of Land Moisture (LM)

<table>
<thead>
<tr>
<th>No</th>
<th>NDSI</th>
<th>NDVI</th>
<th>NDWI</th>
<th>LM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0.016</td>
<td>0.193</td>
<td>0.180</td>
<td>4.6</td>
</tr>
<tr>
<td>3</td>
<td>0.008</td>
<td>0.177</td>
<td>0.246</td>
<td>14.1</td>
</tr>
<tr>
<td>5</td>
<td>0.002</td>
<td>0.260</td>
<td>0.329</td>
<td>9.9</td>
</tr>
<tr>
<td>7</td>
<td>0.122</td>
<td>0.270</td>
<td>0.275</td>
<td>24.7</td>
</tr>
<tr>
<td>9</td>
<td>0.075</td>
<td>0.318</td>
<td>0.357</td>
<td>48.4</td>
</tr>
<tr>
<td>12</td>
<td>0.170</td>
<td>0.352</td>
<td>0.342</td>
<td>26.1</td>
</tr>
<tr>
<td>13</td>
<td>0.117</td>
<td>0.411</td>
<td>0.394</td>
<td>34.2</td>
</tr>
<tr>
<td>17</td>
<td>0.069</td>
<td>0.392</td>
<td>0.472</td>
<td>36.6</td>
</tr>
<tr>
<td>20</td>
<td>0.194</td>
<td>0.394</td>
<td>0.378</td>
<td>33.5</td>
</tr>
<tr>
<td>22</td>
<td>0.069</td>
<td>0.440</td>
<td>0.519</td>
<td>61.4</td>
</tr>
<tr>
<td>23</td>
<td>0.267</td>
<td>0.383</td>
<td>0.381</td>
<td>66.7</td>
</tr>
<tr>
<td>26</td>
<td>0.319</td>
<td>0.617</td>
<td>0.555</td>
<td>72.8</td>
</tr>
</tbody>
</table>

LM : Land Moisture in % at 0-20 cm soil depth

All figure show that all index own positive respon to increase of land moisture, but NDVI more sensitive with stronger correlation. Increasing NDVI is related with vegetation cover, so land with closed canopy relative own more moisture condition than land with less vegetation.

Result of correlation result among 3 indices are shown on Table 3-2.

Table 3-2. Correlation coefficients among NDSI, NDVI, and NDWI

<table>
<thead>
<tr>
<th>NDSI</th>
<th>NDVI</th>
<th>NDWI</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDSI</td>
<td>1</td>
<td>0.81*</td>
</tr>
<tr>
<td>NDVI</td>
<td>1</td>
<td>0.86*</td>
</tr>
</tbody>
</table>

*significant at 5 % level

NDVI have significant correlation with NDSI and NDWI, because there are interactions among reflectances which formed 3 indices.
Result of the multiple linear regression between 3 indices and land moisture (LM) before conducted principle component transformation shown below:

\[ LM = 11.5481 + 137.4587 \times \text{NDSI} - 55.8609 \times \text{NDVI} + 141.4911 \times \text{NDWI} \]  

\( n = 26; R^2 = 0.81; Se = 9.1; t1 = 3.23*, t2 = -0.94, t3 = 3.07^* \)  

\( 3-1 \)
The result shows that influence of NDVI variable not significant if used together with other indices to estimate land moisture directly. NDVI has weak sensitive onto land with have less vegetation, but own high moisture because there was rain before. Research result by Wang (2005) shows only produce correlation about 0.65 between NDVI and soil moisture.

3.2. Principle Component Analysis of 3 Indices
Based on results mention above, so for obtaining better result to estimate land moisture need to do principle component transformation. The result of the first principle component which contains almost information of 3 indices can be used as new index called Land Moisture Index (LMI) with equation:

\[ LMI = 0.484 \times NDSI + 0.687 \times NDVI + 0.542 \times NDWI \]

(3-2)

Scatterplot result between LMI and Land Moisture (LM) on Figure 3-4 shows positive relationship between both, where increasing of LM also followed by increasing of LMI.

3.3. Finding The Best of Estimation Model and Implementation
The best of estimation model for estimating land moisture by using LMI can be obtained trough running simulation model of non linear regression. To get optimum result, dependent or independent variable can be transformed into new variable by using mathematical operation. Finally, an estimation model in exponential form has been developed to estimate land moisture (LM) condition for the agricultural land with equation 3-3. The scatterplot result between LLM and 1/LMI is shown on Figure 3-5.

\[ LM = 172.2145 \times \exp (-0.76102/LMI) \]

(3-3)

\[ n = 26 \; ; \; R^2 = 0.825 \; ; \; Se = 0.30 \; ; \; t-test = 10.4** \]

This equation result is better than equation 3-2, because have \( R^2 \) higher and smaller Se. The equation is also better than model estimation which produced by Dirgahayu (2005) that uses reflectances combination of R1,R2, and R6 with \( R^2 = 0.81 \).

The implementation of model can be created land moisture distributon spatially at paddy field until district level by using MODIS data (Figure 3-6). Potential drought can be predicted based on land moisture, where area which have moisture <= 30 % will be occurred drought condition and more 30 % for expecting the early growing season.

IV. CONCLUSION
(1) Land Moisture Index (LMI) which is derived from the first principle component of 3 indices MODIS (NDSI, NDVI, and NDWI) is the best parameters to estimate Land Moisture (LM) with equation:

\[ LM = 172.2145 \times \exp (-0.76102/LMI) \; ; \; \text{where} \; LMI = 0.484 \times NDSI + 0.687 \times NDVI + 0.542 \times NDWI \]

(2) LM can be used as one of indicator to detect drought condition and early growing season of agricultural crops.
Figure 3-5. The Relationship between LMI MODIS and Land Moisture

Figure 3-6. Spatial Distribution of Land Moisture on 2nd Weekly of August 2005 at Bekasi, Karawang District, West Java

REFERENCES

