Surface Energy Balance Method into Remote Sensing Application and GIS for Drought Monitoring in Bandung, Indonesia

Laras Tursilowati, Josaphat Tetuko Sri Sumantyo, Hiroaki Kuze, and Erna Sri Adiningsih

Center for Environmental Remote Sensing (CEReS), Chiba University, Japan
National Institute of Aeronautics and Space (LAPAN), Indonesia.

Corresponding Author: Laras Tursilowati

Abstract
Current progress of remote sensing technology capable describe the spatial scale can be used as a drought monitoring. The purpose of this research are to analyze variables used for monitoring drought such as Latent heat flux (L), Bowen Ratio (BR), Evaporative Fraction (EF), and Evapotranspiration (ET), using Surface Energy Balance (SEB) method from Landsat 7 ETM satellite and GIS application. The drought monitoring in Indonesia especially Bandung that located in tropical region is very important, because the drought area in dry season is increasingly widespread that indicated by reduced of water sources, irrigation, fisheries and groundwater. The land cover classification result in Bandung dominated by plantation (49%), then forest 19%, open land 14%, residence 9%, paddy field 6%, water body 2%, cloud 2%, and industry 0.7%. The high value of L, ET and EF was found in vegetated area (forest, plantation, paddy field), water body, and cloud, and otherwise low value in the dry (non-vegetated) area (residence, industry and open land). Instead of BR value will low in the vegetated area and water body, cloud and high in non-vegetated area.

Keywords: drought, surface energy balance, landsat 7 ETM satellite, GIS

INTRODUCTION
Drought is a problem that often arises in Indonesia during the dry season arrives. Various methods of drought monitoring with satellite remote sensing data have been implemented. Vogt et al. (1998), Niemeyer and Vogt (1999) describe concept that is the energy balance and Evaporative Fraction (EF) for monitoring drought in the region Sicilia. EF is the ratio between the energy to do with the difference in evapotranspiration net radiation with energy to move the heat in the soil. On the ground condition do not contain water, energy for evapotranspiration (ET) decreased so that EF decreased. In this case the lower the evaporative fraction, then the drought level will be higher. The opposite of the concept of EF is the Bowen Ratio (BR), which explains that the higher the value of BR will be higher levels of dryness of the land. According to the National Disaster Management Agency (BNPB), Saguling lake located in Bandung regency including one of 20 large reservoirs in Indonesia that alert status (actual water level elevations greater than elevation standby drought but smaller than normal elevation). Agricultural land in the district of Bandung which experienced drought due to dry season is increasingly widespread (Tribunnews, 2011). Land-use and land-cover are major factors in the heat budgets on regional and local climate scales. Natural changes in land-cover occur due to the growth or reduction of vegetation cover with seasons as well as climate anomalies, such as seasonal drying or drought events.

Human land-use also affects land cover through agriculture and urban development (Lyons et al., 1993, Zaitchik et al., 2006). A number of heat budget studies have been conducted (Garcia et al., 2007, Meijerink et al., 2005, Sobrino et al., 2005), each employing a different technique to calculate the surface heat budget. ET is a combination of evaporation from the soil surface by transpiration from plants. ET is one of the main components in the hydrological cycle with respect to the calculation of water availability. The purely remote sensing based estimates of evaporative fraction and actual evapotranspiration shows high accuracy and a good seasonal dynamic when compared to field measurements (Stisen, 2007).

The purpose of this study is to use the concept of surface energy balance (SEB) for the detection of drought potential in Bandung. Use of satellite imagery in the acquisition of spatial data has been shown to provide accurate and efficient. From the Landsat 7 ETM data can be estimated Latent heat flux (L) and BR, which play an important role in the calculation of Penman ET in the study area Bandung, West Java. This study will estimate ET, L, BR and EF based on the method of SEB. The results of processing the data were analyzed with Geographic Information Systems (GIS). Statistical Product and Service Solution (SPSS) software was used to analyze correlation and regression model of EF, BR, L, and ET.
RESEARCH METHODOLOGIES

Study Area

Bandung, the capital of West Java province, located about 180 km (112 miles) southeast of Jakarta, is the fourth largest city in Indonesia (Figure 1). With over 2.9 million population in 2007 and over 7.2 million people on the greater Bandung regency and metropolitan area, it's one of the most densely populated city in Asia. It's rated the fastest-growing major city/urban region in Indonesia.

Figure 1. Map of Bandung (Data source: Bandung City Web Site)

The basin’s main river is the Citarum, one of its branches, the Cikapundung, divides Bandung from north to south before it merges with Citarum again in Dayeuhkolot. The Bandung basin is an important source of water for drinking water, irrigation and fisheries, and its 6,147 million m³ of groundwater is a major reservoir for the city. Due to its elevation, the climate in Bandung is cooler than most Indonesian cities with the average temperature is 23.6 °C throughout the year. (The Official Bandung City Web Site, 2011, The Official Bandung Regency Web Site, 2011).

Data and Tools

The data used in the study were as follows: Landsat 7 ETM with covered Bandung area (Path 122, Row 065) dated 22 December 2001 with the acquisition LI/G format, digital map of Bandung administration, digital maps of Bandung land use. The required software tools used for processing data consist of ER Mapper 7, Arc View GIS 3.3 and SPSS 13.

METHODOLOGY

Landcover Classification of Bandung

Some stages are performed on the 7 ETM satellite image processing: Image Restoration, Image Enhancement, Cropping Study area, Geometric and Radiometric Correction (non-thermal/visible band). After the initial process of Landsat 7 ETM satellite image data processing, and then land classification processing using the Unsupervised Classification method to get some type of land cover in Bandung, which include: residence, paddy fields, forest, plantation, industry, open land, water bodies (lakes, rivers, reservoirs), and clouds.

Estimation of Latent Heat Flux, Evaporative Fraction, Bowen Ratio, and Evapotranspiration

The source of energy that drives the earth’s climate comes from the electromagnetic radiation emitted from the sun (Liou, 2002). The net radiation is the amount of energy available to do work at the surface of the earth as it is converted into heat. The redistribution of this energy across the earth’s surface is accomplished primarily through three processes. These are first, Sensible heat flux (H), which is the process where heat is transferred from the Earth’s surface to the atmosphere by conduction and convection. Secondly, L moves energy when solid and liquid water are converted into vapour. Finally Ground heat flux (G), is the transfer of sensible heat in the soil towards the surface or away from the surface. Net radiation (Rn) is total of shortwave radiation that income minus longwave radiation that leave from surface. The following equation describes the partitioning of heat energy at the earth’s surface (Monteith and Unsworth, 1990, Qi et al., 1998)

\[ Rn = H + G + L, \]  
(1)

where, \( Rn, H, G, \) and \( L \) in W/m².

Measurements of \( L \) and \( H \) in the atmospheric boundary layer are useful for understanding processes in agriculture and meteorology and also for management applications. To identify the potential for drought to the concept of energy balance is the Evaporative Fraction (Niemeyer and Vogt, 1999, Wang and Cribb, 2006). In this concept \( EF \) is getting low, the potential of drought will be higher. The equation for calculating \( EF \) is as follows (Vogt et al., 1998),

\[ EF = \frac{L}{Rn - G}, \]  
(2)

\( EF \) values ranged between 0-1 and the greater the \( EF \) the more potentially wet area and the smaller the value of \( EF \) potentially increasing the dry area. The parameters that can identify potential drought is using Bowen ratio. Like the \( EF \) value of \( BR \) is also often used to perform detection of a land that is experiencing shortages of water. \( BR \) has the opposite value with \( EF \), the greater value of \( BR \) means higher potential for drought. The Bowen ratio (Bowen, 1926), is defined as the ratio of the energy available for sensible heating to energy available for latent heating. \( BR \) is measured as the ratio of the gradients of temperature and vapor pressure across two fixed heights above the surface. All fluxes are positive downward. \( BR \) system is applied under the assumption that the turbulent transfer coefficients for sensible heat and water vapor are equal (Pielke, 2001). Formula to calculate the \( BR \) is as follows (Kakane and Agyei, 2006),

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Based on the practical calculation, Allen et al., 1998 in Kotsopoulos et al. (2003) stated one W/m² from heating the water vapor flux (L) will be able to evaporate the water of 0.035 mm/d. The energy used for evaporotranspiration is the amount of radiation energy is reduced by the net energy used to heat the air (H) and the energy to heat the soil (G). This means that the energy for evaporotranspiration will be even greater if the same amount of net radiation heat transfer was (H) and energy used to heat the soil (G) is low. But also energy for evaporotranspiration will be even greater if the value of the net radiation if the soil heat flux and sensible heat flux small. This means the amount of energy for evaporotranspiration is influenced by surface temperature and albedo of an area. ET estimated from equation (Allen et al., 1989, Allen, 2005, Yang et al., 1997):

\[ ET = \frac{Rn - G - H}{\rho w \lambda} \]

where ET in mm/d, \( \rho w \) is water density (1000 kg/m³), and \( \lambda \) is vapor latent heat (28.2 W/kg). The Penman-Monteith also form of the combination ET equation (Allen et al., 1989, Allen, 2005, Barbagallo et al., 2009, Mavi and Tupper, 2004, Sumner and Jacobs, 2005) as:

\[ ET = \frac{\Delta (R_n - G) + \rho_v \beta \gamma \frac{r_s - r_a}{r_a}}{\Delta + \gamma \left(1 + \frac{r_s}{r_a}\right)} \]

where ET in mm/d, \( R_n \) in (MJ m⁻² d⁻¹), \( G \) in (MJ m⁻² d⁻¹), \( \Delta \) is the vapor pressure deficit of the air (kPa), \( \rho_v \) is saturation vapor pressure of the air (kPa), \( r_s \) is the mean air density at constant pressure (kg m⁻³), \( c_p \) is the specific heat of the air (MJ/(kg °C)), \( \gamma \) is the psychometric constant (kPa°C), \( r_s \) is the bulk surface resistance (s/m), \( r_a \) is the aerodynamic resistance (s/m), \( \lambda \) is latent heat of vaporization (MJ/kg), \( k_{sw} \) is a unit conversion (86,400 s/d for ET in mm/d and 3600 s/h for ET in mm/h) (Kotsopoulos et al., 2003, Sumner and Jacobs, 2005).

**RESULT AND DISCUSSION**

**Landcover Classification**

From the results of the classification of land with unsupervised method which has been validated by the survey results, the obtained spatial maps of land classification shown in Figure 1, and statistically it could be shown by Figure 2. Surveyed areas representing seven types of land cover, there are residence, industry, open land, water body, plantation, paddy field, and forest. The total area of the Bandung classification results is about 282,525 ha. Bandung area dominated by 49% plantations (137388 ha), then 19% forest (52835 ha), 14% open land (38457 ha), 9% residence (25118 ha), 6% paddy field (17188 ha), 2% cloud (4987 ha), 2% water body (4678 ha), and 0.7% industry (1875 ha). Urban area consisting of residential, industrial and open land located in the downtown, marked with red, purple, and yellow colors. Urban areas also spread around Cimahi, Lake Saguling, Padalarang, Lembang, and the suburbs. Land cover types of water body are marked with blue color in the Lake Saguling in the western part of Bandung. Forest predominantly located in the southern part of Bandung, and a small portion in the northeast of Bandung. Plantations spread in all regions except in the down town. Paddy field mostly located in the eastern part of Bandung, and in the northern part of Bandung there is a cloud cover.
Figure 3. Latent Heat Flux ($L$) (W/m²)

$L$ average on the land cover types from highest to lowest are in the forest which is 151 W/m², then the plantation (102 W/m²), cloud (35 W/m²), water body (34 W/m²), paddy field (25 W/m²), open land (14 W/m²), industry (5 W/m²), and the last on residence (4 W/m²).

**Bowen Ratio ($BR$)**
Bowen ratio is the ratio between $H$ with $L$ which is usually used for the identification of potential drought in a region, the higher of $BR$ value then the higher the potential drought in the region. $BR$ values are spatially depicted in Figure 5 with value from high to low are 4 in the urban areas (residence, industry and open land), 0.5 in the plantation, 0.33 in the forest, 0.25 in the paddy field, and 0.11 in the water body and cloud. This means that the urban area has potential drought is higher than other regions.

**Evaporative Fraction ($EF$)**
The opposite of the Bowen ratio, evaporative fraction is shown the level of wetness of a region. Figure 6 is map of the distribution of evaporative fraction in Bandung. Spatially seen that the use of the land settlements have high levels of evaporative fraction compared with vegetation and wet area.

**Evapotranspiration ($ET$)**
Distribution of Bandung Evapotranspiration estimation from satellite data spatially is shown in Figure 7 and the boxplot of $ET$ in the difference for land cover types shown by Figure 8.
The pattern of spatial distribution of evapotranspiration in the Bandung area shows high evapotranspiration located on vegetated land or water and otherwise lower value on dry land or non-vegetation. Boxplot in Figure 8 can show the difference in the value of each land cover. Evapotranspiration average from high to low are forest (5.3 mm/d), plantation (3.6 mm/d), water body and cloud (1.2 mm/d), paddy field (0.9 mm/d), open land (0.5 mm/d), industry (0.2 mm/d), and residence (0.1 mm/d). Likewise, if the distribution pattern of ET compared to L seen there the resemblance, namely that if the high value of L will be higher the value ET, and vice versa.

Statistical Analysis
Statistical Product and Service Solution (SPSS) software was used to analyze correlation of ET, BR, L, and ET. Cohen 1988 in Pallant (2007) suggest the following guidelines of correlation interpretations as small ($r = 0.10$ to $0.29$), medium ($r = 0.30$ to $0.49$), and large ($r = 0.50$ to $1.0$). For regression analysis used stepwise method which decisions about the order in predictors are based on a purely mathematical criterion. The computer then searches for the predictor (out of the ones available) that best predicts the outcome variable. If this predictor significantly improves the ability of the model to predict the outcome, then this predictor is retained in the model and the computer searches for a second predictor. The criterion used for selecting this second predictor is the variable that has the largest semi-partial correlation with the outcome (Field, 2005, Morgan et al., 2004). The Pearson correlation of ET, BR, L, and ET with two-tailed significance levels was shown in Table 1. There is large positive correlation between $L$ and ET ($r = 1$), large negative correlation between BR and ET ($r = -0.98$). Slightly large negative correlation ($r = -0.5$) between $L$ and BR also between ET and BR. Medium positive correlation ($r = 0.38$) between $L$ and ET, ET and EF, also EF and L.

### Table 1. Pearson correlation between $L$, ET, BR and EF

<table>
<thead>
<tr>
<th></th>
<th>$L$</th>
<th>ET</th>
<th>BR</th>
<th>EF</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L$</td>
<td>1</td>
<td>1.000</td>
<td>-0.501</td>
<td>0.380</td>
</tr>
<tr>
<td>ET</td>
<td>1.000</td>
<td>1</td>
<td>-0.501</td>
<td>0.379</td>
</tr>
<tr>
<td>BR</td>
<td>-0.501</td>
<td>-0.501</td>
<td>1</td>
<td>-0.982</td>
</tr>
<tr>
<td>EF</td>
<td>0.380</td>
<td>0.379</td>
<td>-0.982</td>
<td>1</td>
</tr>
</tbody>
</table>

Correlation is significant at the 0.01 level
Number of data : 65535

### Table 2. Regression Analysis between $L$, ET, BR and EF

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>(Constant)</td>
<td>5.158</td>
<td>0.004</td>
<td>1411.0</td>
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<tr>
<td></td>
<td>EF</td>
<td>-6.632</td>
<td>0.006</td>
<td>-0.980</td>
</tr>
<tr>
<td>2</td>
<td>(Constant)</td>
<td>5.168</td>
<td>0.003</td>
<td>1711.6</td>
</tr>
<tr>
<td></td>
<td>EF</td>
<td>-6.269</td>
<td>0.005</td>
<td>-0.926</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>-0.003</td>
<td>0.000</td>
<td>-0.125</td>
</tr>
</tbody>
</table>

1. Dependent Variable: BR

Table 2 represent that the regression analysis between $L$, ET, BR and EF using stepwise method. EF variables first included in the model, then the variable $L$. At this point the process stops, it means there is one variable (ET) is not included in the model because ET did not significantly affect to BR. $t$ calculated for the EF $1711.6$, with probability (Sig) is smaller than the significance level ($0.0 < 0.05$), mean $EF$ significant influence. $t$ calculated for $L$ - $1241.2$ with probability (Sig) $0.0 < 0.05$, means $L$ a significant effect. So that the resulting empirical regression equation models are:

\[
BR = 5.168 - 6.269(\text{EF}) - 0.003(\text{L}) \quad (7)
\]

### CONCLUSIONS

The drought monitoring in Bandung based on surface energy balance (SEB) method has been done by using remote sensing (Landsat 7 ETM satellite data) combined with GIS. The total area of the Bandung classification results is about 282,525 ha. In 2001 the Bandung area dominated by plantations (49%), then forest (19%), open land (14%), residence (9%), paddy field (6% or), cloud (2%), and water body (2%). Bowen Ratio (BR) is the ratio between Sensible heat flux ($H$) with energy for Evapotranspiration (ET) which is usually used for the identification of potential drought in a region. The opposite of the BR, Evaporative Fraction (EF) is shown the level of wetness of a region. Latent heat fluxes ($L$) and EF will be high on the vegetated land (forest, plantation, paddy field) or waterbodies, and vice versa will be low if the land is in non-vegetation (open land, residential, and industrial). Otherwise BR in urban land cover with less vegetation has a higher value than the vegetated land and water bodies, so that in urban areas have a high potential for drought in comparison with land cover that other. According to the difference in energy balance, ET in urban area land cover have a lower value than the land cover.
characteristics of water. Monitoring of potential ET has important implications in the hydrological cycle and forecast environmental changes that affect the forest and agricultural ecosystems. The regression equation models are \( BR = 5.168 - 6.269 (EF) - 0.003 (L) \).

It is revealed that the results of this study can explain that if there is a change of vegetation land to residential (urban) will increase the energy to heat the air and reduce evapotranspiration. This resulted with the level of drought will be high. Maintaining a balance between vegetation and buildings in urban areas needs to be done, so that the preservation of nature in balance. Besides many advantages remote sensing for monitoring drought, there are disadvantages and limitations. The disadvantages are many sensors in Landsat 7 ETM satellites that need to be calibrated and adjusted carefully and accurately (Campbell, 1987), the limitations of clear sky data in the tropics such as Indonesia because the weather constraints, difficulty in interpretation of data (need to understand the theory, measurement uncertainty, knowledge of atmospheric phenomena), the high cost to build, operate and data acquisition.

REFERENCES

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