SEBAL Model to Estimate Biophysics and Energy Flux Variable: Availability of Evapotranspiration Distribution Using Remote Sensing in Lore Lindu National Park

A Munawir¹, T June², C Kusmana³, Y Setiawan⁴

¹ Forestry and Environmental Science Faculty, Halu Oleo University, Indonesia
² Faculty of Mathematics and Natural Science, Bogor Agricultural University, Indonesia
³ Department of Natural Resources and Environment Management, Graduate School, Bogor Agricultural University, Indonesia
⁴ Faculty of Forestry, Bogor Agricultural University, Indonesia

Email: abdillahmunawir@uho.ac.id

Abstract. Lore Lindu National Park or Taman Nasional Lore Lindu (TNLL) is a natural resource conservation area with various potentials of endemic flora and fauna diversity. This study aimed to estimate the value and spatial distribution of biophysical factors, energy flux, and evapotranspiration. This method used the Surface Energy Balance Algorithm for Land (SEBAL) model and performs the pessimistic, moderate, and optimistic scenarios. The number of measured parameters includes biophysical variables and energy flux variables. The results showed that the average value of evapotranspiration in forest areas was higher than open land or other land uses. The evapotranspiration values in the three images varied between 0.07 - 0.20 mm/hour. The dry month evapotranspiration in 2002 was 17%-32% higher than the dry months in 2013 and 2018. The build on the energy flux and evapotranspiration models results into the value of energy flux and evapotranspiration explanation in TNLL. The results can be controlled with efforts of increasing reforestation of forest land cover by 10%, controlling population growth by 1% per year, and increasing public awareness by 10%. This situation concludes that uncontrolled changes in forest land function and population growth in TNLL have an effect on changes in energy flux and evapotranspiration.

1. Introduction

1.1. Background

SEBAL was first formulated by [1]. The published paper describes the stages of SEBAL formulation. The SEBAL algorithm estimates the spatial variation empirically of the main hydro-meteorological parameters [2,3]. It requires satellite imagery data [4], surface temperatures [5], and plant height [3,6]. The SEBAL model calculates flux from each land cover [3,8] and can be used to process infrared thermal images at a resolution of meters to kilometers [15]. This model determines empirical relationships for each parameter adjusted for geographic location and time of image acquisition [8,9]. Lore Lindu National Park or Taman Nasional Lore Lindu (TNLL) is a forest area to protect endemic flora and fauna [10]. The very high land-use changes in the TNLL area from 2002 to 2013 caused the loss of 2507 Ha of natural forest that changed its function as land for plantation crops, agricultural cultivation, and settlements [10,16]. It is important to know the estimation of evapotranspiration. Evapotranspiration is the process of water loss from a land cover through evaporation from the soil surface and transpiration from the plant surface [11,12].
The main advantage of applying remote sensing for evapotranspiration analysis is the estimation. Remote sensing in SEBAL model can be derived directly without calculating complex hydrological processes [2,13]. Spatial tools such as GIS allow for large-scale management of interrelated spatial information and the ability to integrate and analyze information from layers [8,9]. From climatological studies for forest areas and other land uses [22], evapotranspiration largely determines the trend of plant water availability in forest areas and other land uses [18]. On the other hand, evapotranspiration is calculated by measuring several surface parameters, including surface albedo, surface temperature, surface emissivity, soil heat flux, surface roughness, net radiation, air temperature gradient (dT), felt heat flux, and latent heat flux [1,23]. Thus, it is very important to study the estimation of energy flux and evapotranspiration on various factors in TNLL using the SEBAL method and system dynamics [2,13]. Identifying the estimated energy flux and evapotranspiration, that affect the rate of forest land cover depletion and building a forecast model for the availability of evapotranspiration in the next few years, will provide space for efforts to control forest land cover depletion. Thus, the function of the TNLL forest area can be well maintained.

1.2. Aim
This study aimed to estimate the value and spatial distribution of biophysical factors, energy flux, and evapotranspiration in the Lore Lindu National Park (TNLL), Central Sulawesi Province, Indonesia.

2. Methodology

2.1. Date and Study Site
The location of this study was carried out in Lore Lindu National Park (TNLL), Central Sulawesi Province, Indonesia, with a geographical location between 119° 58' - 120° 16’ east longitude and 1° 8’ - 1° 3’ south latitude. Administratively, TNLL is located in two regencies, namely Sigi Regency, precisely in the Districts of Sigi Biromaru, Palolo, Nokilalaki, Tanambulava, Gumbasa, Lindu, Kulawi, and South Kulawi covering an area of 112,792.08 ha (52.28%). Meanwhile, Poso Regency is located in the Districts of North Lore, Lore Paore, Central Lore, West Lore and South Lore with an area of 102,941.62 ha (47.72%). TNLL is established through the Decree of the Minister of Forestry and Plantations No. 464/Kpts-II/1999 dated 28 June 1999.

The research was conducted in Lore Lindu National Park, Central Sulawesi Province, starting from April to November 2020.

Figure 1. Study Area Map in Lore Lindu National Park.

2.2. Type of Data
The main data used in this study were satellite images obtained during the recording period of Landsat 7 in 2002, Landsat 8 in 2013, and 2018 (line/line 114/61 with < 10% cloud cover obtained from http://earthexplorer.usgs.gov/). Landsat 7 and Landsat 8 image data that have undergone radiometric
processing are then processed by statistical analysis of the Surface Energy Balance Algorithm for Land (SEBAL). Each satellite image data will estimate the distribution of evapotranspiration calculated using three software, namely ERDAS 2014, Google Earth Pro, and ArcGIS 10.5. Statistical analysis was carried out using the statistical functions of Microsoft Excel and SPSS 21.0. The model scenario data uses Powersim Professional 10 software to see forecasts for pessimistic, moderate, and optimistic scenarios.

2.3. Image Processing and Spatial Analysis
This study was carried out using remote sensing spatial analysis. The delineation of the study was carried out by employing several digital image processing techniques. Land cover in the study area was analyzed in the temporal period (2002, 2013, and 2018). Landsat image processing begins with a description of the research location based on ecological boundaries using a map of the boundaries of the TNLL area of the Ministry of Environment and Forestry. Geometric correction is the process of transforming data from a grid coordinate system to the earth using a geometric transformation [21]. It is done because the image data used have different coordinates so that the projected image becomes UTM (Universal Transverse Mercator) Zone 50 S and datum WGS 84 (World Geographic System 84) using ArcGIS 10.5 software. Radiometric correction is the process of making corrections to pixel values that are distorted due to atmospheric factors. It needs to be done to get the actual pixel value at the right position, the atmospheric effect that causes the reflection of objects on the earth’s surface to have a DN value that is different from the actual value. Atmospheric factors that will be corrected are errors in reflecting the surface or curvature of the earth, the direction of sunlight, weather conditions, atmospheric conditions, and other factors so that the information provided is more accurate [22]. The remote sensing analysis data were further classified and calculated changes in each land cover using spatial analysis techniques. The mentioned spatial analysis in this study describes the results of the analysis of NDVI, SAVI, PV, LAI, Albedo, LST, Rn, G, Zo, U*, Rah, H, and evapotranspiration (ET). The calculation of the coverage of each parameter using the SEBAL test from 2002, 2013, and 2018 was analyzed spatially using ArcGIS.

2.4. Statistical Analysis
Statistical analysis used Arc GIS 10.5 software, Erdas Imagine spatial analysis software, and EXCEL. Statistical information on the SEBAL Model in the study was collected and visualized to show the trend of the proportion of the estimated energy flux and different evapotranspiration/cover areas from 2002-2013-2018. Average proportions were measured using ArcGIS 10.5, pixel values of the determinant variables, NDVI, SAVI, Albedo, Ts, Rn, G, H, LE, and ET, gained through remote sensing modeling and in raster image format, extracted and sorted by type land use/cover in EXCEL for statistical analysis. The mean values of the determinants by different land cover types were calculated and illustrated to show temporal dynamics aligned with the mapped spatial pattern. With the extracted pixel values, correlation analysis was taken between the determinant variables, including the four pairs, NDVI/Albedo, –Ln(Zo), LAI, h, Rn-G, H+LE, Ts, dT, α–Ts, Ts – ET, dan ET-NDVI, with software, EXCEL, SPSS, and Arc Gis can observe the relationship of the main components in the regional climate system. More specifically, land cover within the area and outside the TNLL area is analyzed separately to discover the effects of human activities such as agriculture and urbanization processes on the regional climate environment through land-use change. The absolute values of the lower and higher Pearson correlation coefficients at the 95% confidence level between variables derived from a range of land cover within and outside the TNLL area were used to perform the t-test in SPSS.

3. Results and Discussion

3.1. Energy Flux of TNLL
The TNLL area covers an area of 229,000 ha based on the second Instruction Letter by the Minister of Forestry No. 593/Kpts-II/1993 dated October 5, 1993. Then, in 1999, measurements and definitive boundaries were made through the Decree of the Minister of Forestry and Plantations No.464/kpts-
II/1999 dated July 28, 1999, the area of Lore Lindu National Park was officially set at 217,991.18 Ha. The results of the energy flux calculation as many as two five parameters in the TNLL forest area in Central Sulawesi Province show a decrease in energy flux and evapotranspiration (Table 1) with the average value from the calculation results of Landsat 7 and Landsat 8 images in 2002, 2013, and 2018.

Table 1. Energy Flux Calculation Parameter Value in 2002, 2013, and 2018

| Year | NDVI | SAVI | LAI | Ts  | Rn  | G    | H    | LE  | ET  | NDVI/Albedo |
|------|------|------|-----|-----|-----|------|------|-----|-----|-------------|
| 2002 | 0.8  | 0.62 | 2.4 | 29.2 | 231.52 | 9.67 | 69.52 | 198.68 | 0.2 | 6.11         |
| 2013 | 0.723| 0.59 | 2.12| 30.57| 197.21 | 10.40| 84.42 | 83.16 | 0.17| 5.85        |
| 2018 | 0.7  | 0.55 | 1.65| 31.75| 164.5  | 10.75| 91.67 | 58.35 | 0.13| 5.17        |

Minimum 0.7 | 0.55 | 1.65 | 29.21 | 164.5 | 9.67 | 69.52 | 58.35 | 0.13 | 5.85 |
Maximum 0.8 | 0.62 | 2.4 | 31.75 | 231.52 | 10.75 | 91.67 | 198.68 | 0.2 | 6.11 |
Mean 0.74 | 0.59 | 2.06| 30.51 | 197.74 | 10.27 | 81.87 | 113.4 | 0.17 | 5.71 |
Standard Deviation 0.02 | 0.04 | 0.52 | 1.63 | 48.53 | 0.63 | 4.71 | 45.25 | 0.07 | 0.65 |

We determined the data based on the analysis results in Table 2 from Landsat 7 ETM+ image data, the acquisition date of 28 September 2002 and Landsat 8 imagery, the acquisition date of 20 October 2013 and 16 November 2018. It shows that the NDVI estimation in the TNLL area uses Landsat imagery using the NIR band and the red band as NDVI estimation on other vegetation [3,11]. The NDVI results show that there is a relationship between NDVI and SAVI where the greater the amount of vegetation, the more dense the plant crowns are. The NDVI values in the TNLL area in 2002, 2013, and 2018 were -0.11 ± 0.80, -0.32 ± 0.723, -0.17 ± 0.7 followed by SAVI values of -0.05 ± 0.62, 0.39 ± 0.59, -0.09 ± 0.55. It can indicate that NDVI and SAVI will increase with increasing the amount of plant vegetation density. On the other hand, a decrease in the vegetation amount will result in a decrease in the NDVI and SAVI value.

The albedo value was obtained from processing the Landsat 7 ETM+ image data in 2002 and Landsat 8 in 2013 and 2018. Table 2 shows a description of the albedo in 2002, 2013, and 2018 in the TNLL area.

Figure 2. Surface Temperature (LST) TNLL in 2002, 2013, and 2018

The estimated surface temperature is extracted from Band 6 on Landsat 7 and Band 10 on Landsat 8, which is the thermal band on Landsat imagery. Band 6 and Band 10 record surface emission at
wavelengths 10.4–12.5 m (Landsat 7) and wavelengths 10.30–12.50 (Landsat 8). Estimation of surface temperature is obtained from the emissivity correction (Equation 5) where the emissivity value for vegetated land is assumed to be around 0.95 (Weng, 2001). The average surface temperature of the TNLL area in September 2002 was 11.16°C ± 29.21°C, in October 2013 it was 7.9°C ± 30.57°C, and in September 2018 it was 9.5°C ± 31.75°C (Figure 3). Based on these results, it can be seen that the surface temperature in the TNLL area shows fluctuations in the increase in surface temperature in the period 2002, 2013, and 2018. This condition explains that there has been a change in land cover in the TNLL area for several years, mainly forest areas as described in [11,20], that there has been a decrease in changes in the forest area of TNLL from year to year.

The surface temperature in September 2002 was 1.36°C lower than in October 2013. This is due to the increase in the surface temperature value depending on the intensity of the incoming radiation [3,19]. The incoming short-wave radiation is greater in value than the incoming long-wave radiation, so to see the results of surface temperatures in several months in several years, it can be seen from the value of incoming short-wave radiation [11].

3.2. Evapotranspiration (ET) Estimates Using SEBAL Model
Calculation of evapotranspiration is important. It can determine the amount of consumptive water use for plants, analysis of water availability, and pump capacity for irrigation [22]. According to [21], the factors that affect evapotranspiration are weather parameters, plant factors, management, and environmental aspects. The spatial distribution of evapotranspiration shows in September 2002 with values ranging from 0.1701 to 0.2254 mm/hour, in November 2013 evapotranspiration values tend to decrease with values ranging from 0.1602 to 0.2215 mm/hour. In September 2018, the evapotranspiration value ranged from 0.12607 to 0.2256 mm/hour. In general, the average value of evapotranspiration based on the value of the LE/RN ratio in the dry month of 2002 was 86% higher than the dry month of 2013, which was 42%, and decreased in 2018 by 35% (Table 2), compatible with results [2] Land surface temperature will increase with decrease the amount of vegetation density [3,23].

Table 2. Percentage of Net Radiation Amount for Process Water Vapor Flux

| Year | LE (WM²) | RN (WM²) | Ratio LE/RN (%) |
|------|----------|----------|-----------------|
| 2002 | 198.68   | 231.52   | 86              |
| 2013 | 83.16    | 197.21   | 42              |
| 2018 | 58.35    | 164.5    | 35              |

Figure 3. Change in Evapotranspiration and Latent Heat in 2002–2018.

Latent heat flux represents the portion of evapotranspiration derived from the energy balance, which will always go to equilibrium along with other energy fluxes [21]. Evaporation from a surface can be well determined if all the components that affect the energy balance on the surface, be it net radiation (Rn), felt heat flux (H) and soil heat flux (G) is known [3]. For the TNLL region, [22] found that forest areas undergoing land changes caused a decrease in monthly evapotranspiration of around 2%. It shows
that land changes in forest areas resulted in a decrease in evapotranspiration every year in the TNLL area.

3.3. Energy Flux Estimation and Evapotranspiration Forecast Model in TNLL

In the TNLL area, according to population data from 15 villages, it shows that the population in 2002 was 137 people [20] and increased significantly in 2018 to 683 people with an annual population growth rate of 2.7%. Graphically the population growth is shown in Figure 4.

![Population Increase and Decline in Forest TNLL from 2002-2018.](image)

The simulation results of the existing model show that the increase in occupation has an impact on the decline in forest areas [23]. On the other hand, population growth is followed by an increase in built-up land, agriculture, and plantations, which in 2013 has reduced the forest area of TNLL [10]. Moderate
scenario model (BAU) is a model that illustrates conditions without any intervention on the model showing that an increase in temperature of 34.46°C has an impact on changes in latent heat flux of 45.40 Wm-2 and evapotranspiration of 0.10 mm/hour. The pessimistic scenario model is a scenario that illustrates the occurrence of population growth from 2.0% to 2.5% per year. The results of the model scenario show that an increase in temperature of 36.43°C has an impact on changes in the value of latent heat flux to 39.66 Wm-2 and evapotranspiration to 0.09 mm/hour. The optimistic scenario model is a scenario that illustrates the occurrence of an increase in forest land cover from the results of a 10% forest area reforestation policy, a 10% increase in public awareness, and the BKKBN program at 1% per year. This model shows a decrease in temperature to 30.70°C, resulting in a change in latent heat flux to 51.00 Wm-2 and evapotranspiration to 0.12 mm/hour.

4. Conclusion

The increase in temperature fluctuations in the range of 23°C to 33°C indicates that changes in forest land in TNLL have an impact on changes in energy fluxes. It threatens the existence of endemic flora and fauna in TNLL. The evapotranspiration value has the same pattern as the latent heat flux. The latent heat flux is a partition of the energy balance with the ratio of LE/Rn in the dry period of September 2002 and November 2013 of 86% and 42%, while in the dry period of September 2018 it was 35%. This value is used to estimate the water needs of the TNLL area. Based on the study of the SEBAL method, in the dry period of September 2002 the average daytime evapotranspiration value was 0.1701 – 0.2254 mm/hour and the average in November 2013 was 0.1662 – 0.2215 mm/hour. While in the dry period of September 2018 the average during the day was 0.12607 – 0.2256 mm/hour.
The Lore Lindu National Park (TNLL) management scenario model is carried out with 3 approaches (Moderate, Pessimistic, Optimistic). Moderate scenario model (BAU) is a model that depicts conditions without any intervention on the model showing that an increase in temperature of 34.46°C has an impact on latent heat flux of 45.40 Wm-2 and evapotranspiration of 0.10 mm/hour. The pessimistic scenario model is a scenario that illustrates the occurrence of population growth from 2.0% to 2.5% per year. The scenario model shows that an increase in temperature of 36.43°C has an impact on the value of latent heat flux to 39.66 Wm-2 and evapotranspiration to 0.09 mm/hour. The optimistic scenario model is a scenario that illustrates the occurrence of an increase in forest land cover from the results of a 10% forest area reforestation policy, a 10% increase in public awareness, and the BKKBN program at 1% per year. This model shows a decrease in temperature to 30.70°C, resulting in a change in latent heat flux to 51.00 Wm-2 and evapotranspiration to 0.12 mm/hour.

5. References

[1] Bastiaanssen WGM, Menenti M, Feddes RA, Holtslag AAM. 1998 A remote sensing surface energy balance algorithm for land (SEBAL) 1 formulation. Journal of Hydrology. 212: 198-212.
[2] Bastiaanssen WGM. 2000. SEBAL-based sensible and latent heat fluxes in the irrigated Gediz Basin, Turkey. Journal of Hydrology. 229: 87-100.
[3] Sabajo CR, Maire GL, June T, Meijide A, Roupard O, Knohl A. 2017. Expansion of oil palm and other cash crops causes an increase of the land surface temperature in the Jambi province in Indonesia. Biogeosciences. 14 : 4619 4635.
[4] Liang, S 2000 Narrowband to broadband conversions of land surface albedo I: Algorithms, Remote Sens. Environ., 76, 213–238, https://doi.org/10.1016/S0034-4257(00)00205-4.
[5] Jiang, Y, Fu P and Weng 2015 Assessing the Impacts of Urbanization-Associated Land Use/Cover Change on Land Surface Temperature and Surface Moisture: A Case Study in the Midwestern United States, Remote Sens., 7, 4880–4898, https://doi.org/10.3390/rs70404880
[6] Wang C, Glenn N F 2008 A linear regression method for tree canopy height estimation using airborne lidar data. Can. J. Remote Sensing. 34 (2): 217-227.
[7] Anderson J E, Thomas A, Douglass, Robyn A B, Stephanie Saari, Jarrod D E, Robert M J 2019 Linking vegetation cover and seasonal thaw depths in interior Alaska permafrost terrains using remote sensing. Journal Remote Sensing of Enviroment 233 (2019) 111363. Elsevier Procedia.
[8] Xiao X, Boles S, Frolking S Li C, Babu J Y, Salas W, Moore B 2004 Mapping Paddy Rice Agriculture in Southern China Using Multi-Temporal MODIS Image. J Remote Sens of Environment. 100 : 95–113.

[9] Li, Y, Zhao M, Motesharre S, Mu Q, Kalnay E, and Li S: Local cooling and warming effects of forests based on satellite observations, Nat. Commun., 6 6603, https://doi.org/10.1038/ncomms7603, 2015.

[10] Munawir A, June T, Kusmana C, Setiawan Y 2019 Dynamics Factors that Affect the land Use Change in the Lore Lindu National Park. Proceeding of SPIE 11372. Event: Sixth Internasional Symposium on LAPAN-IPB Satelite. Bogor (ID).

[11] June T, Meijide A, Stiegler C, Kusuma AP, Knohl A 2018 The influence of surface roughness and turbulence on heat fluxes from an oil palm plantation in Jambi, Indonesia. IOP Conf. Series: Earth and Environmental Science. 149: 1-11.

[12] Allen, R G, Tasumi M Morse A, Trezza R, Wright J L, Bastiaanssen, W, Kramber W, Lorite I, and Robinson C W 2007 Satellite-Based Energy Balance for Mapping Evapotranspiration with Internalized Calibration (METRIC)- Applications. Journal of Irrigation and Drainage Engineering, 133, 395-406. http://dx.doi.org/10.1061/(ASCE)0733-9437 133:4(395).

[13] Beg AAF, Al-Suttani A H, Ochtyra A J A, Marcinkowska A 2016 Estimation of evapotranspiration using SEBAL algorithm and Landsat-8 data - a case study : Tatra Mountains Region. Journal of Geological Resource and Engineering. 6 : 257-270.

[14] Hunt E R, Daughtry C S T, Eitel J U H, Long D S 2011. Remote sensing leaf chlorophyll content using a visible band index. Agronomy Journal 103, 1090–1099.

[15] Margono, B. A., Turubanova, S., Zhuravleva, I., Potapov, P., Tyukavina, A., Baccini, A., Goetz, S., and Hansen, M. C.: Mapping and monitoring deforestation and forest degradation in Sumatra (India) using Landsat time series data sets from 1990 to 2010, Environ. Res. Lett., 7, 34010, https://doi.org/10.1088/1748-9326/7/3/034010, 2012.

[16] Stefan E, André T, Muhammad A, Adam M and Martin K 2004 Mapping deforestation and land cover conversion At the rainforest margin in central sulawesi, indonesia. EARSeL eProceedings 3, 3/2004.

[17] Lillesand TM, Kiefer RW, Chipman JW 2004. Remote Sensing and Image Interpretation. Fifth Edition. Denver (US): John Wiley & Sons, Inc.

[18] Achard F, Eva H D, Mayaux P, Stibig H J, Belward A 2004 Improved estimates of net carbon emissions from land cover change in the tropics for the 1990s. Global Biogeochem. Cycles 18, 1–11.doi:10.1029/2003 GB002142.

[19] Artikanur S D, June T 2019 Surface Temperature and Heat Fluxes: Comparison between Natural Forest and Oil Palm Plantation in Jambi Province Using Surface Energy Balance Algorithm for Land (SEBAL). Agromet 33(2), 62-70. https://doi.org/10.29244/j.agromet..

[20] Badan Pusat Statistik 2002 Penjelasan Teknis Data Podes Palu Sulawesi Tengah.

[21] Allen R G, Pereira L S, Raes D, Smith M 1998 Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56.

[22] Li Y, Huang,C, Hou J, Gu J, Zhu G, Li X 2017 Mapping daily evapotranspiration based on spatiotemporal fusion of ASTER and MODIS images over irrigated agricultural areas in the Heihe River Basin, Northwest China. Agricultural and Forest Meteorology 244 82–97.

[23] Allen RG, Tasumi M, Trezza R, Waters R, Bastiaanssen WGM 2002 Surface Energy Balance Algorithms for Land. Idaho(US) : Idaho Implementation.