Critical land mapping for the development of biomass-based energy in East Lombok Regency, Indonesia

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Abstract. Utilization of critical land as woody biomass plantations need to be supported by information on the potential of critical land. The objective of this research was to delineate a critical land using remote sensing and GIS techniques combined with Analytical Hierarchy Process method. The parameters used were land use/cover, slope, rainfall erosivity, tolerable soil erosion, soil erodibility, land management, and land productivity. The Analytical Hierarchy Process method was used to provide the weight of each parameter. Land use/cover map was interpreted from SPOT-7 satellite imageries acquired in 2017. The other parameter maps were built based on reference maps, secondary and field data collection as well as soil sample analysis. The resulted map showed that 32.7% area of East Lombok Regency was categorized as a critical area. Based on the land status, the critical land area located in the State Forest was smaller (42%) than on the Area for Other Utilization (58%). Utilization of critical land as woody biomass plantation should be prioritized on the shrub-covered land using community forest scheme, while for the area of State Forest, the plantation can be only planted in the production forest area applying industrial plantation forest or community plantation forest scheme.

1. Introduction
Increasing energy demand is commonly accompanied by higher pollution and greenhouse gas emissions [1]. Dominantly use of fossil energy sources tends to increase the CO₂ content in the air and leads to global warming and climate change that are increasingly felt in this century [2]. To overcome this global issue, coupled with the prediction of fossil fuel reserve depletion, the use of renewable energy is encouraged including energy from woody biomass. Biomass plantation is very potential to be developed because providing multiple benefits such as bioenergy production, carbon sequestration and regaining ecosystem services [3]. Biomass energy is predicted to be a driver of growth in
renewable energy because biomass can be developed almost anywhere, and biomass energy can be produced on demand [4].

East Lombok Regency currently has the largest consumption of wood-based bioenergy in the form of firewood compared to other districts. This firewood is used for household consumption, small scale industries, and the largest proportion is used for Virginia tobacco industries [5]. Currently, the use of energy wood is dominantly used as firewood and in the future potential to be developed as a substitute fuel in power plants gradually replacing fossil fuels.

To supply woody biomass for fulfilling the increasing energy demand, more land resources are required to expand the woody plantation. East Lombok as an agrarian area with high population density, has limited land area to be cultivated as a bioenergy source. The arable land will be prioritized as agricultural’s areas to produce more food to feed the growing population. Therefore, Indonesia Government proposed to utilize critical land as expandable areas for biomass plantation development. The use of the critical area as woody plantation can avoid the conflict between food and energy production. The international trend is tending to scale up the optimization use of critical land as fast-growing woody plantation specifically as a source of power plant fuel. Many of them are developed on the local and small scale to anticipate the fluctuations of economic appropriateness level of produced energy [6,7,8,9,10,11].

Currently, the information of critical land on a medium or detail scale for the development of biomass plantation has not been mapped. The government has released critical land map at the national level that comes from small-scale map inputs so that it is necessary to classify critical land based on the quality and productivity of the land. Several methods in delineating critical land are still a trend that continues to be developed by researchers. The use of remote sensing and GIS techniques is the most extensive method in classifying a kind of degraded land and desertification. The important parameters involved in this method are continued to be developed. Some adjustments were made between the affecting parameters and the specific characteristics of the observed ecosystem observed [12]. The level of importance among the parameters can be easily characterized using the AHP method, a robust and flexible decision-making method in finding solutions such as in the case of erosion level determination [13,14,15]. Therefore, the objective of this research was to delineate a critical land area using remote sensing and GIS techniques based on AHP weighted parameters.

2. Materials and Methods

2.1. Research area

East Lombok is a regency in Nusa Tenggara Barat province located at the east part of Lombok Island. As shown in Fig.1, astronomically the position is between 116˚ - 117˚ east longitudes and 8˚ - 9˚ south latitudes. The land occupies about 161 thousand km² (33.9% area of Lombok Island), laying from mountainous area with 3,726-meter altitude up to coastal area, and 60% of the area has 2 – 15% slope.

![Figure 1. Research area](image-url)
Most of the land is utilized as agricultural land. East Lombok consists of 20 districts, and it has the largest population compared to the other regencies in the provinces. In 2017, the population number was about 1.2 million, with a density of 737 inhabitants/km², and 0.8% population growth. East Lombok has a tropical climate with 31 – 33°C average maximum temperature and 22 – 25 °C average minimum temperature. In 2017, the annual rainfall 1580 mm with 109 rainy days [16]. Based on soil type, East Lombok has five soil ordo with 14 soil types in the great-group category. The main soil ordo namely Andisol, Inceptisol, Entisol, Alfisol, and Aridisol. Inceptisol has the largest area with 56,791.7 ha or 55.4% of all area, followed by Alfisol with 19,779.9 ha or 19.3% [17].

2.2. Data

In determination of critical land level, firstly the object area (East Lombok Regency) was divided into three specific function areas: (a) protected forest and conservation forest, (b) production forest area, and protected area outside the state forest area, and (c) agriculture cultivation area, and area for other utilization. The division was based on the guidance of critical land mapping from Ministry of Forestry that was changed in 2018. East Lombok Regency was divided into three categories based on the map of forest area status, combined with the map of Official Spatial Land Use Plan (OSLUP). Determination of critical land for each specific area was based on a set of parameter maps namely land use/cover, rainfall erosivity (R), slope (S), tolerable soil erosion (T), soil erodibility (K), land management, and land productivity. Those parameters were determined through expert discussion to eliminate the weaknesses of previous guidance [18].

Land use/cover map was delineated from the interpretation of SPOT-7 satellite imageries acquired in 2017. The interpretation was done using on-screen digitizing in ArcGIS software. The pan-sharpened mode was used with a spatial of resolution 1.5 m, and the result accuracy was assessed by field check and verified using available QuickBird imageries from 2015.

Rainfall erosivity map indicates the effect of rainfall intensity on soil erosion [19]. It was built based on monthly rainfall data, a number of rainy days and maximum daily precipitation in a certain month. Ten years rainfall data from 16 rain gauge stations were obtained from Agricultural and Livestock Services of East Lombok Regency. The erosivity was calculated using Bols [20] as in equations (1) and (2).

\[
R = \sum_{m=1}^{12} R_m
\]

\[
R_m = 6.119 \times (\text{Rain})^{1.21} \times (\text{Days})^{-0.47} \times (\text{Max})^{0.53}
\]

Where Rm is average monthly rainfall erosivity; (Rain)m is average monthly rainfall (cm); (Days)m is a number of rainy days in a certain month; (Max)m is average maximum daily rainfall in a certain month (cm). Distribution of erosivity in the study area was mapped using the interpolation technique in the ArcGIS software.

The slope map was derived from 8 m resolution DEM acquired from the Geospatial Information Agency, Indonesia. The analysis was done using the 3D analyst tool in ArcGIS software, and the result was classified into five class: < 8, 8-15, 16-25, 26-40, and > 40%. Soil characteristic maps at scale 1:50,000 used in this research were obtained from Agricultural Land Resource Agency. Based on those maps, East Lombok regency was divided into 75 land mapping units. To complete physical soil characteristics needed for generating critical land parameter maps, soil samples were taken from the field using soil core sampler tools. Soil properties involve five fractions of soil texture, bulk density, permeability, and organic matter content were analyzed in the laboratory of Soil Research Institute, Ministry of Agriculture using standard laboratory methods [21].

Tolerable soil erosion (T) indicates the maximum allowable erosion rate that soil fertility and productivity still can be maintained [22,23]. T was calculated based on [24] equation (3).
Where,

\[ T = \left( \frac{D_{e} - D_{\text{min}}}{S} + F \right) \times BD \]  \hspace{1cm} (3)

- \( D_{e} \): soil effective depth (cm) x soil depth factor
- \( D_{\text{min}} \): minimum soil depth for plant root (cm)
- \( S \): soil sustainability (300 years)
- \( F \): rate of soil formation (1 – 1.5 cm/year depending on the soil type)
- \( BD \): bulk density (gr/cm\(^3\))

Soil erodibility (K) reflected soil susceptibility to the erosion is one of the important factors in determining soil erosion using USLE and RUSLE model [25]. The value varies from 0 to 1; lower K value indicates less prone to soil erosion [26]. Equation (4) was used to determine K value based on soil texture (% of silt, sand, and very fine sand), soil organic matter content, soil structure, and permeability [19,27].

\[ K = \frac{2.713 \left( M^{1.14} \right)(10^{-4})(12-a) + 3.25(b-2) + 2.5(c-3)}{100} \]  \hspace{1cm} (4)

- \( M \): (very fine sand % + silt %) x (100 – clay %)
- \( a \): organic matter content (%)
- \( b \): soil structure code: (1) very structured or particulate; (2) fairly structured; (3) slightly structured, and (4) solid
- \( c \): soil permeability code: (1) rapid; (2) moderate to rapid; (3) moderate; (4) moderate to slow; (5) slow, and (6) very slow

Land management map was built based on secondary data acquired from Dodokan Moyosari Watershed Management Institute. In this parameter, land management in each district was scored based on completeness of land boundary markers, activities to secure the land, extension activities, and application of soil and water conservation. This data was validated based on field observation and interview with the related stakeholders.

Land productivity map is one of the parameters used to assess the critical land in an agricultural cultivation area. In this parameter, land productivity score was carried out based on a comparison between the average annual production of rice and maze with optimal production that can be reached. These data sources were acquired from Agricultural and Livestock Services [16].

2.3. Analysis

Each parameter for a certain specific function area was weighted using the analytical hierarchy process (AHP). The AHP, developed by the mathematician Thomas L. Saaty, was conducted by fulfilling a set of the questionnaire by eleven experts. The questionnaire consists of pairwise comparisons between the parameters, and the experts valued using a scale of 1 to 9 [28,29].

Scoring for each parameter was done based on parameter values resulted in the previous steps. The scoring used value 1 (for the worst condition) up to 5 (for the best condition). GIS analysis to delineate the critical land was done by overlaying all prepared thematic maps according to each area status. Total values for each land mapping unit were resulted from overlay operation in ArcGIS software or known as weighted index overlay [26,30]. This operation would result in the total value range from 100 to 500 and the critical land was categorized into five levels: severe critical (100 – 180), critical (181 – 260), moderately critical (261 – 340), potentially critical (341 – 420), and uncritical (421 – 500).
3. Results and Discussion

Land use/cover map resulted from remote sensing analysis was shown in figure 2. The map indicated that East Lombok area was dominated by agricultural land (44%), followed by forested land (25%). In East Lombok, agricultural land can be found in the form of dryland agriculture, shrub - mixed dryland agriculture, and paddy field as the largest portion. Based on tabular data in table 1, East Lombok also has unutilized land covers included shrub, grassland, and barren land with 14% of total area. On the other hand, plantation forest has the smallest area compared to the others. In East Lombok, there is only one private company manages plantation forest producing energy wood. Other energy woods are produced by the community in the form of the community forest. Utilization of unproductive land cover as plantation forest will help this regency to fulfill its biomass energy from sustainable sources.

![Figure 2. Land use/cover map](image)

| Land use/cover                      | Area (ha) | %  |
|------------------------------------|-----------|----|
| Dryland Forest                     | 39,062    | 24.3 |
| Plantation Forest                  | 426       | 0.3 |
| Mangrove                           | 1,680     | 1.0 |
| Mixed Plantation                   | 15,539    | 9.7 |
| Dryland Agriculture                | 11,020    | 6.9 |
| Shrub-mixed Dryland Agriculture    | 15,949    | 9.9 |
| Paddy Field                        | 43,647    | 27.1 |
| Shrub                              | 14,681    | 9.1 |
| Grassland                          | 6,439     | 4.0 |
| Barren Land                        | 1,482     | 0.9 |
| Settlement                         | 9,021     | 5.6 |
Land use/cover condition often can be used as a simple mark of critical land. Based on the weight of parameter resulted from AHP in table 2, land use/cover was the highest weight especially in the protected and conservation forest area. Deforestation affecting the reducing of forest covers was mainly due to the opening of forest for dryland farming and the massive of illegal logging. Forest conversion becomes agricultural land was also caused by higher pressure to the productive agricultural land which was often converted to build up area [29].

| Parameter                      | Weighting factor for each parameter |
|--------------------------------|-------------------------------------|
| Protected and conservation forest | 0.254 0.184 -                        |
| Production forest area and state forest | 0.192 0.278 0.183                |
| Agriculture cultivation area and area for other utilization | 0.206 0.157 0.162 |
| Tolerable soil erosion         | 0.094 0.107 0.108                  |
| Soil erodibility               | 0.122 0.137 0.148                  |
| Land management                | 0.134 0.137 0.128                  |
| Land productivity              | -                                  |
| Source: the result of analysis |

The other parameter maps built to classify critical land were listed in figure 3. Based on the slope map in figure 3a, topographic characteristic of East Lombok area was dominated by the steep slope in the north parts and slightly flat slope in the south parts. Table 2 indicates that the slope parameter has a big role in determining critical land. It has the highest weight in the protected area outside the state forest area, and production forest area. Rainfall erosivity map in the figure 3b showed that estimated erosivity value ranges from 711 to 2687. The west part of East Lombok regency with relatively higher annual rainfall has the highest rainfall erosivity value.

Map of soil erodibility as shown in figure 3c was generated based on soil texture, organic matter content, permeability, and soil structure. These values were retrieved from soil characteristics stated in the soil map, completed trough soil sample analysis, and the result was listed in table 3. Using equation (4), calculation of K value was range between 0.15 and 0.38. The lower K value indicates low permeability value and also affected by soil texture.

| Variable of analysis | Value range |
|----------------------|-------------|
| Organic C (%)        | 1.0 2.7     |
| Silt (%)             | 14.4 53.3   |
| Clay (%)             | 27.3 51.4   |
| Sand (%)             | 13.7 46.2   |
| Very fine sand (%)   | 1.7 4.7     |
| Bulk density (gr/cm³)| 1.1 1.4     |
| Permeability (cm/hour)| 1.8 58.4   |
| Source: the result of soil sample analysis |
Tolerable soil erosion (T) in figure 3d indicated that area in East Lombok mainly has low T value (<25 ton/ha/yr). The area with low T values needs more attention because only a minor erosion will affect serious consequences and will aggravate critical land level, especially in hilly areas with a steep slope and shallow solum [31].

Land management map in figure 3e showed that north area of East Lombok relatively has better land management compared to other areas. North area is dominated by state forest area that has better completeness of land boundary markers, higher extension activities, and more applied of soil and water conservation. For the land productivity in the cultivation area, as shown in figure 3f, the center part of East Lombok has higher productivity. This area is dominated by Typic Eutru dioxide soil type with good characteristics [17] coupled with good water supply.
GIS analysis has been carried out to delineate the critical land level. Distribution and level of degraded land in East Lombok is presented in figure 4.

![Figure 4 Distribution of critical land levels](image)

Critical land in East Lombok consists of three levels i.e. moderately critical, critical, and severe critical. Those critical level also can be divided based on the ecological status of the area during scoring and weighting process. Finally, those critical land area can be categorized based on the status of forest area as stated in table 4.

**Table 4. Area of critical land (in hectare)**

| Critical level     | Protected and conservation forest (State Forest Area) | Protected area outside the state forest area and production forest area | Agriculture cultivation area, and Area for Other Utilization (Non-Forest Area) | Total | %     |
|--------------------|------------------------------------------------------|-------------------------------------------------------------------------|-------------------------------------------------------------------------------|-------|-------|
|                    | State Forest Area | Non-Forest Area |                                                                                   |                          |       |
| Moderately Critical| 13,036 | 3,635 | 14,023 | 15,110 | 45,804 | 87.04 |
| Critical           | 4,589  | 776   | 880   | 560    | 6,805  | 12.93 |
| Severe Critical    | 4      | 11    | 14    | 0.03   |        |       |
| Total              | 17,629 | 4,411 | 14,914 | 15,670 | 52,623 | 32.70 |
| %                  | 33.50  | 8.38  | 28.34  | 29.78  | 100    |       |

*percentage from the total area of regency
Source: the result of analysis
The map resulted from this research showed that 32.7% or 52,623 ha area of East Lombok Regency was categorized as critical land. Although 32.7% is a quite large portion area in a regency, need a more analytical procedure to assess available critical land for producing woody biomass. Based on the area calculation of critical land map intersected with land use/cover map and land status, indicated that the critical land area was distributed on several land use/cover types. The distribution was dominantly located in agricultural land (50.3%) and followed by shrub (22.4%), while, based on the land status, the critical land located in the State Forest Area was smaller (42%) than on the area for other utilization (58%).

In the development of woody biomass plantation, it should be considered to prioritize the utilization of degraded land covered by shrub or other unutilized lands such as grassland and barren land. On the Area for Other Utilization, the biomass plantation can be built using community forest scheme, while for the State Forest Area, the plantation can be only planted in the production forest area using industrial plantation forest or community plantation forest schemes. Although critical land is not an ideal land for farming, optimized management practices can support biomass productivity. The management includes the use of suitable species [31], optimized fertilizer inputs, harvesting time management, and available water handling. Utilization of water resource is not only the concern in biomass production but also a critical issue for environmental sustainability [7].

4. Conclusion
The map resulted from this research showed that East Lombok Regency has 32.7% area of critical lands. Those critical land are dominantly located in agricultural land (50.3%) and shrub (22.4%), while based on the land status, they are located in the area of State Forest (42%) and Area for Other Utilization (58%). Utilization of critical land as woody biomass plantation should be prioritized on the shrub-covered land using community forest scheme, while for the area of State Forest, the plantation can be only planted in the production forest area applying industrial plantation forest or community plantation forest scheme. Further research will assess suitable land and species for the biomass plantation development.

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