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Assessment of critical land using geographic information systems - a case study of Limboto watershed, Gorontalo

Muhammad Ramdhan Ollii¹, Ilyas Ichsan¹

¹Department of Civil Engineering, University of Gorontalo, Gorontalo, 96211, Indonesia

E-mail: kakaramdhanolii@gmail.com

Abstract. Limboto is one of the watersheds in Indonesia that have suffered considerable damage. The degradation of Limboto Watershed was caused by extended land allocation for dry land agriculture that does not regard conservation practices, especially for corn as the main commodity from Gorontalo. Watershed degradation is directly proportional to an increase in critical land affected by various factors, which are land use, slope, and soil erosion. The aim of this research is to assess and to represent the spatial distribution of critical land in the Limboto Watershed based on the Directorate-General of Watershed Management and Forest Protection Regulation Number P.3/PDASHL/SET/KUM.1/7/2018 on the Technical Guidelines for the Drafting Spatial Data on Critical Land. The factors of critical land were collected and processed through a geographic information system (GIS)-based approach. The results of this study indicated that the Limboto Watershed is dominated by land of rather critical class. This provides useful information for decision makers and the local government to take appropriate land management measures in Limboto Watershed.

Keywords: Critical Land, Limboto Watershed, GIS, Spatial Distribution.

1. Introduction

Ministry of Forestry Decree Number 52/KPTS-II/2001 defines critical land as land for which its physical condition is as such that the land does not function properly according to its designation as a medium for production or water management [1]. The boundaries are determined both inside and outside forest areas. In 2013, the Directorate-General of Watershed Management and Protected Forest Management issued Regulation Number P.4/V-SET/2013 on the Technical Guidelines for Drafting Spatial Data on Critical Land based on Ministry of Forestry Regulation Number P.32/MENHUT-II/2009 on the Procedures for the Preparation of Technical Plans for Forest and Land Rehabilitation in Watersheds [2]. In 2018, the regulation was revised by the Directorate-General of Watershed Management and Forest Protection with the issuance of Regulation Number P.3/PDASLH/SET/KUM.1/7/2018 on the Technical Guidelines for Drafting Spatial Data on Critical Land with the following considerations: (a) the number of parameters used in the previous technical guidelines needed to be further simplified by reducing the number of utilized parameters; (b) the method used in the previous technical guidelines tended to result in parameter repetition, whether by weight or score, and thus needed to be refined; (c) the data used in the previous technical guidelines only relied on vector data and thus needed to be improved by using raster data [3]. Changes in instructions related to determining critical land will lead to differences in results, which will also affect future watershed management policies.
The Limboto Watershed was one of the Priority Watersheds in the Watershed and Protection Forest Management Office of Bone Bolango Working Area from 2008-2012, because the Limboto Watershed Ecosystem underwent a very severe damage process. On June 12, 2009, Ministry of Forestry Decree Number SK 328/Menhut-II/2009 was issued; the decree concerns the Determining of Priority Watersheds in the Framework of the Medium-Term Development Plan for 2010-2014. Limboto Watershed became one of the 108 Priority Watersheds in Indonesia. In the Limboto Watershed, there is one lake, Lake Limboto, which is threatened by extinction due to the shrinking and shallowing of the lake that was quite significant due to land erosion that occurred in the upstream part of the watershed. Lake Limboto is an estuary of five major rivers: Alopohu, Meluopo, Bionga, Marisa, and Rintenga; water also flows into approximately 23 tributaries, which are likely to bring about erosion. If this occurs continuously, then the shrinkage and siltation of Lake Limboto due to soil erosion becomes greater, causing flooding around Lake Limboto due to the reduction in the volume of the reservoir capacity of Lake Limboto. Damage and increased erosion are directly proportional to the area of critical land that is present around the Limboto Watershed.

The purpose of this study is to assess the spatial distribution of critical land for the Limboto Watershed, while the benefit is to aid relevant parties in the interest of conserving water resources so that critical land disasters can be prevented and better controlled.

2. Materials and Methods

2.1. Materials

To achieve the aim of this research, the following datasets were collected: (1) daily precipitation of 5 rain-gauge stations from 1998 to 2018, collected from the Meteorological, Climatological, and Geophysical Agency of Indonesia; (2) 120 soil samples from field, which were used to find out the soil texture, as sand, silt, and clay; (3) SRTM DEM with a spatial resolution of 30 m of the area, downloaded from https://earthexplorer.usgs.gov; and (4) a land use map taken from the Office of Watershed Management and Protection Forest of Bone Bolango.

2.2. Methods

The target of land criticality assessment were for land with land functions related to reforestation and afforestation activities, as forests, nature tourism parks, nature reserves, wildlife reserves, community forests, hunting parks, and national parks. A flowchart for determining the critical land level can be seen in Figure 1.

![Figure 1. Flowchart for determining critical land level](image-url)
The procedure for determining critical land was based on the Directorate-General of Watershed Management and Forest Protection Regulation Number P.3/PDASLH/SET/KUM.1/7/2018 on the Technical Guidelines for Drafting Spatial Data on Critical Land, with the following steps:

(1) The land cover map was divided into 5 classes based on the classification of Malingreau et al. (1981) [4]. Furthermore, the grading of scores was based on the weight of the land cover parameter (60) multiplied by the land cover class, then divided by the total number of classes (Table 1).

| No. | Land Cover Type | Class | Score |
|-----|-----------------|-------|-------|
| 1.  | Airport         |       |       |
| 2.  | Body of water   |       |       |
| 3.  | Swamp           |       |       |
| 4.  | Savana          |       |       |
| 5.  | Settlement/transmigration area |       |       |
| 6.  | Primary dry land forest | 1 | 12 |
| 7.  | Rice fields     |       |       |
| 8.  | Fish ponds      |       |       |
| 9.  | Primary mangrove forest |       |       |
| 10. | Secondary mangrove forest |       |       |
| 11. | Primary swamp forest |       |       |
| 12. | Secondary swamp forest |       |       |
| 13. | Secondary dry land forest | 2 | 24 |
| 14. | Forest plantations |       |       |
| 15. | Plantation      | 3     | 36    |
| 16. | Shrub           |       |       |
| 17. | Swamp groves    | 4     | 48    |
| 18. | Dry land farming|       |       |
| 19. | Mixed dry land farming |       |       |
| 20. | Open land       | 5     | 60    |
| 21. | Mining          |       |       |
| 22. | Cloud           | 0     | 0     |
| 23. | No data         |       |       |

(2) The soil erosion rate was calculated using the USLE/RUSLE method based on Ministry of Forestry Regulation Number P.32/MENHUT-II/2009 on the Procedures for the Preparation of Technical Plans for Forest and Land Rehabilitation in Watersheds. Soil erosion rates were classified based on soil erosion rates for each raster grid and then given a score. The value of the soil erosion class score was based on the weight of the soil erosion parameter (40) multiplied by the sequence number of the soil erosion class, then divided by the total number of soil erosion classes (Table 2).
Table 2. Soil erosion score (40% weight)

| No. | Soil Erosion Class | Soil Erosion Rates (tons ha\(^{-1}\) year\(^{-1}\)) | Score |
|-----|--------------------|---------------------------------------------|-------|
| 1.  | Very Slight        | <15                                        | 8     |
| 2.  | Slight             | 15 – 60                                    | 16    |
| 3.  | Moderate           | 60 – 180                                   | 24    |
| 4.  | Severe             | 180 – 480                                  | 32    |
| 5.  | Very Severe        | >480                                       | 40    |

(3) Classification of lands inside and outside the forest area was carried out on the types of area functions with government permission, specifically the Ministry of Environment and Forestry, on the duties and functions in managing forest areas. The basis of this classification was the data on types of area functions for the thematic functions of regions (Table 3).

Table 3. Division of inside and outside the forest area

| No. | Area Function                             | Description                      |
|-----|------------------------------------------|----------------------------------|
| 1.  | Protected forest                         | Inside the forest area           |
| 2.  | Conservation forest                      |                                  |
| 3.  | Production forest                        |                                  |
| 4.  | Limited production forest                |                                  |
| 5.  | Converted production forest              |                                  |
| 6.  | Natural land tourism park                |                                  |
| 7.  | Nature reserve area                      |                                  |
| 8.  | Marine wildlife sanctuary                 |                                  |
| 9.  | Land nature reserve                      |                                  |
| 10. | Forest park botanical garden             | Inside the forest area           |
| 11. | Nature conservation area                 |                                  |
| 12. | Forest nature reserves and land tourism  |                                  |
| 13. | Forest nature reserves and sea tourism   |                                  |
| 14. | Hunting park                             |                                  |
| 15. | Marine nature park                       |                                  |
| 16. | Marine nature reserve                    |                                  |
| 17. | Land wildlife sanctuary                   |                                  |
| 18. | Land national park                       |                                  |
| 19. | Marine national park                     |                                  |
| 20. | Other land use areas                     | Outside the forest area          |
| 21. | Body of water                            | Body of water                    |

(5) The slope class map was generated from a hypsographic map (contour) or Digital Elevation Model (DEM).

(6) The land cover map and soil erosion class maps were overlaid to obtain the total score for each land unit (Table 4).
Table 4. Slope class map

| No. | Slope Class Type | Slope Class (%) |
|-----|------------------|-----------------|
| 1.  | Flat             | 0 - 8           |
| 2.  | Sloping          | 8 - 15          |
| 3.  | Slightly steep   | 15 - 25         |
| 4.  | Steep            | 25 - 40         |
| 5.  | Very Steep       | >40             |

(7) The overlay of land cover and soil erosion class maps in step (6) was overlaid again with the forest area classification (inside and outside) and slope class maps. The results of the map overlay that illustrate the spatial distribution of critical land classes are shown in Table 5 and Table 6.

Table 5. Analysis scores of critical land inside the forest area

| No. | Slope Class (%) | Critical Land Score |
|-----|-----------------|---------------------|
|     |                 | 0 – 36     | 36 – 52    | 52 – 68 | 68 – 84 | 84 – 100 |
| 1.  | 0 - 8           | NC         | NC         | PC       | C       | VC       |
| 2.  | 8 - 15          | NC         | PC         | RC       | C       | VC       |
| 3.  | 15 - 25         | PC         | RC         | RC       | C       | VC       |
| 4.  | 25 - 40         | RC         | RC         | RC       | C       | VC       |
| 5.  | >40             | RC         | RC         | C        | C       | VC       |

Notes: NC = Not Critical; PC = Potentially Critical; RC = Rather Critical; C = Critical; VC = Very Critical

Table 6. Analysis scores of critical land outside the forest area

| No. | Slope Class (%) | Critical Land Score |
|-----|-----------------|---------------------|
|     |                 | 0 – 36     | 36 – 52    | 52 – 68 | 68 – 84 | 84 – 100 |
| 1.  | 0 - 8           | NC         | NC         | PC       | RC      | C        |
| 2.  | 8 - 15          | NC         | PC         | RC       | C       | VC       |
| 3.  | 15 - 25         | PC         | RC         | RC       | C       | VC       |
| 4.  | 25 - 40         | RC         | RC         | RC       | C       | VC       |
| 5.  | >40             | RC         | RC         | C        | C       | VC       |

Notes: NC = Not Critical; PC = Potentially Critical; RC = Rather Critical; C = Critical; VC = Very Critical

3. Results and Discussion

The study resulted in an in-depth analysis of estimating average soil loss in the Limboto Watershed by using the RUSLE method in a GIS framework. The average annual soil erosion (A) was calculated by multiplying the developed raster data from each RUSLE model (A = R K L S C P) [5]. The average annual R factor values varied from 1430.97 to 1944.56 MJ.mm ha⁻¹ h⁻¹, with a mean value of 1549.81 MJ.mm ha⁻¹ h⁻¹. K factor values were relatively discrete and unsteady due to the coarse resolution of available soil data (120 soil samples). The values mainly ranged from 0.013 to 0.043 t ha h ha⁻¹ MJ⁻¹ mm⁻¹ and the mean value was 0.032 t ha h ha⁻¹ MJ⁻¹ mm⁻¹. The combined spatial distribution of LS factor is generated using the SRTM DEM of the study area. LS factor varied from 0 to 473.73, with a mean value of 27.26. The high LS values were for land along river courses and in mountainous areas. Various studies had found that the LS factor plays very important role in RUSLE while the soil erosion rate and LS factor are the most difficult factors in the RUSLE model [6]. Cover management factor (C) values in the study area varied from 0 to 1 and support practice factor P value was observed.
to be from 0.12 to 1. The spatial distribution of each soil erosion factor and the final RUSLE map displaying the average annual soil erosion class (A) of the Limboto Watershed are shown in Figures 2 and 3.

Figure 2. Soil erosion factors of Limboto Watershed
Figure 3. Spatial distribution maps of critical land parameters

The results of average annual soil erosion rate by category (Table 7) indicated that 59.80% of the study area is in the very slight erosion class (0 – 15 tons ha⁻¹year⁻¹), 24.80% is in the slight soil erosion class (15 – 60 tons ha⁻¹year⁻¹), and 7.97% is in the moderate soil erosion class (60 – 180 tons ha⁻¹year⁻¹). The severe to very severe erosion class accounted for 7.47% of the total area although the percentage of land in the very severe erosion class was only 2.64%. Land in Limboto Watershed is dominated by the sloping class (8 – 15 %), with 21.81%. More than 60% of land in Limboto Watershed have slopes of < 25% (Table 7).

Table 7. Distribution of soil loss class, slope class, and critical land class

| Soil Erosion Class (tons ha⁻¹year⁻¹) | Area (ha) | % of Area | Slope Class (%) | Area (ha) | % of Area | Land Critical Class | Area (ha) | % of Area |
|-------------------------------------|-----------|-----------|-----------------|-----------|-----------|---------------------|-----------|-----------|
| 0 – 15                              | 50302.89  | 59.80     | 0 - 8           | 17915.04  | 21.30     | NC                  | 19524.24  | 23.21     |
| 15 – 60                             | 20861.37  | 24.80     | 8 – 15          | 18342.36  | 21.81     | PC                  | 17272.35  | 20.53     |
| 60 – 180                            | 6671.07   | 7.93      | 15 – 25         | 18108.9   | 21.53     | RC                  | 39156.48  | 46.55     |
| 180 – 480                           | 4063.05   | 4.83      | 25 – 40         | 16798.41  | 19.97     | C                   | 4004.82   | 4.76      |
| >480                                | 2217.87   | 2.64      | >40             | 12951.54  | 15.40     | VC                  | 1221.21   | 1.45      |
|                                    |            |           |                 | BW        |           |                     | 2937.15   | 3.49      |
| Total                              | 84116.25   | 100       | Total           | 84116.25  | 100       | Total              | 84116.25  | 100       |

Notes: NC = Not Critical; PC = Potentially Critical; RC = Rather Critical; C = Critical; VC = Very Critical; BW = Body of Water
The results of the mapping of critical land in the Limboto Watershed showed that 23.21% or 19524.24 ha of the watershed area is not critical, while 20.53% or 17272.35 ha is potentially critical, or if not managed properly can become critical; 46.55% or 39156.48 ha of land has a rather critical status, and 6.21% or 5226.03 ha is critical to very critical. This shows that the Limboto Watershed has a fairly poor biogeophysical condition because it is dominated by land in the rather critical class. Therefore, more intensive land management is needed to prevent land from becoming further critical, and to repair land that is already considered critical. The distribution of critical land in the Limboto Watershed was presented in Figure 3 and Table 7. Olii (2013) analysed critical land in the Limboto Watershed based on Ministry of Forestry Regulation Number P.32/MENHUT-II/2009 on the Procedures for the Preparation of Technical Plans for Forest and Land Rehabilitation in Watersheds and found more than 64% of the land area of Limboto Watershed is rather critical [7]. The results between Ministry of Forestry Regulation Number P.32/MENHUT-II/2009 and the Directorate-General of Watershed Management and Forest Protection Regulation Number P.3/PDASL/SET/KUM.1/7/2018 are different.

Regarding the uses of existing land, the distribution of rather critical land is mainly in areas with a slope of > 15%, which are used by residents as dryland farming locations for growing corn. Others are spread evenly throughout the Limboto Watershed, especially for plantations and shrub planting. This needs attention and proper handling because if this is left unchecked, it will have the potential to worsen the status of the land from somewhat critical to critical. Moreover, the Limboto Watershed has the function of a catchment area, which must be preserved.

4. Conclusion

According to Ministry of Forestry Regulation Number P.32/MENHUT-II/2009, the spatial distribution of land classes in the Limboto Watershed is 22.31% not critical, 20.53% potentially critical, 46.55% rather critical, 4.76% critical, and 1.45% very critical.

Directorate-General of Watershed Management and Forest Protection Regulation Number P.3/PDASL/SET/KUM.1/7/2018 and the GIS techniques described in this study are valuable for understanding the situation of and relationship between critical land and environmental factors, which are useful to formulate and implement conservation programs that will decrease critical land.

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