Effect of land criticality on nutrient availability (case study of Dinoyo sub watershed, Jember regency, Indonesia)

P T Sari¹*, I Indarto¹, M W Sujarwo¹ and M R Romadhon²

¹Magister of Natural Resources and Environmental Management, Post-graduated, University of Jember, East Java, Indonesia
²Department of Agrotechnology, Faculty of Agriculture, University of Jember, East Java, Indonesia
*E-mail: putritunjung36@gmail.com

Abstract. Dinoyo sub-watershed is one of the watersheds that drain water from Argopuro Mountain through the Panti and Rambipuji Districts. Land-use changes in the upstream area have reduced the function of water absorption and increased soil erosion. It causes drought during the dry season and flooding during the rainy season which is a characteristic of critical land. This study aims to map the level of criticality of the Dinoyo sub-watershed area and its relationship to nutrient availability. This study used the scoring and weighting method of four main factors that affect the critical value of land (land cover, slope, management, and erosion level). The layers then executed using the Gis program. The result of this analysis produces a land criticality map. Based on the analysis, the upstream section has high nutrient availability compared to the middle and downstream regions. There are two classes of land criticality, which are rather critical and substantial criticism. The area included in the rather critical was 1,723.34 ha dominated by forest land use. A coffee plantation dominates a sizeable critical area of 2,333.88 ha. From regression analysis showed that organic matter had the most influence on the criticality of land.

1. Introduction
An increasing population will increase the need for food, fiber and housing. If this condition happens in regions where the economy is centered on agriculture, it will cause high competition in land use. Jember Regency is one of the provincial food buffer districts, namely as a national rice barn. The population growth of the Jember Regency in 2017 reached 2,430,187 people, and in 2018 it reached 2,440,714 people. This number increased by 0.43% from the previous year, with a density reaching 741 inhabitants / km². This causes the area of agricultural land decreased by 4,975 Ha or 2.09% [1].

The decrease in the agricultural land area shows the high intensity of the conversion of agricultural land in the area. This condition causes farmers to use watersheds for agricultural land. Watershed is an area that is bounded by topography and slopes, which functions to store and drain water through rivers until empties into the sea [2]. Sub-watershed is part of a watershed that functions to collect rainwater and drain it through tributaries to the main river [3]. The Bedadung Watershed is one of the largest watersheds in Jember Regency, which flow through 16 sub-districts in Jember [4]. Dinoyo Sub Watershed is one of the Bedadung watersheds that drains water from the slopes of Mount Argopuro through the Panti and Rambipuji Districts.
The upstream area of the Dinoyo Sub-watershed is in the Panti sub-district, and the downstream is in the Rambipuji sub-district. Upstream areas are conservation areas that function to catch rainwater and become water catchment areas. The land-use changes in the upstream area cause a reduction in water catchment function and increase soil erosion. Erosion is the event of destruction and movement of soil particles from one area to another through surface runoff [5]. Erosion will make the land critical. Critical land is the condition of land that is physically or chemically, unable to support plant growth. The carrying capacity of the land is very low. That makes the ability to store water is low and all rainwater that falls flows into the river [6]. This condition causes drought in the dry season and flooding in the rainy season in the Dinoyo Sub-watershed.

In 2009, hundreds of houses in three sub-districts were flooded. Floods are scattered in Panti, Rambipuji, and Kaliwates sub-districts, all of which are Dinoyo Sub-Watershed which overflowed due to heavy rains in the upstream area in the Panti sub-district [7]. Radar Jember also stated that the drought had reached the urban area of Jember [8]. On 14 September 2019, the Regional Disaster Management Agency (BPDB) distributed clean water to residents in the Patrang sub-district, Jember Regency. Based on data compiled on 1-6 September 2019, there were ten drought disaster points in Jember.

Good Watershed management is very important to provide freshwater that has good quality and quantity. Improper land management can cause land degradation, which propagates a decrease in soil productivity [9]. Intensive and continuous tillage will cause soil compaction, damage the aggregate and pore space [10]. Excessive use of chemical fertilizers such as urea will produce nitrate residues that can survive in the soil and accumulate for several decades [11]. Other impacts are acidification, organic matter content <2%, and nutrient content, and cation exchange capacity is deficient [12] [13].

An assessment of land criticality and its relationship to nutrient availability is needed as a basis for determining appropriate land management. Sustainable watershed management will ensure the availability of good water and food. It can be prevented from drought in the dry season and floods in the rainy season.

2. Material and Methods

2.1. Material

The materials used in this study are (1) rainfall data with recording period from 2008-2018, (2) soil map, (3) land use map, (4) digital elevation models (DEM), and (5) field survey questionnaire. Equipment used for analysis includes (1) Laboratory analysis equipments, (2) Arc-GIS software, and (5) Statistical Package for the Social Science (SPSS) software. Data processing was carried out at the Soil Fertility Laboratory, Faculty of Agriculture, University of Jember.

2.2. Methods

2.2.1 Making Land Unit Map (SPL)

A land unit map is used to determine the sampling point at the research location. Land unit map is made by overlaying 3 basic maps, namely soil type maps, land use maps, and slope maps. The overlay results show that 18 areas represent each particular land condition (fig. 1).
2.2.2 Surveying and soil sampling
The survey was conducted in the Dinoyo Sub-watershed area. It to assess field conditions and obtain information about crop management patterns in the Dinoyo Sub-watershed. It can be additional information for determining management recommendations. Soil sampling is done at each SPL with 3 replication and then compiled at each SPL. Soil sampling is done at a depth of 0-30 cm. The most effective soil chemical parameters found at that depth [14]. The sampling using a purposive sampling method. It can represent the whole research area [15].

2.2.3 Analysis of soil chemical properties
Soil samples that have been taken labeled according to the date and land unit map (SPL). The sample is then dried and analyzed in a laboratory [16]. The chemical parameters are the following:

| Observation parameters         | Analysis Method          |
|-------------------------------|--------------------------|
| Nitrogen total                | Kjeldahl                 |
| Soil organic carbon           | Kurmis                   |
| Phosphor- available           | Olsen                    |
| Potassium- available          | Percolate with NH4Oac 1 M pH 7 |

2.2.4 Erosion rate calculation
The erosion rate calculation is used to determine the effect of crop management on the value of erosion in the Dinoyo Sub-watershed and as data in land criticality analysis. The erosion calculation was performed using the Universal Soil Loss Equation (USLE) method with the following equation [17]:

\[ A = R \times K \times L \times S \times CP \]

Information:
\( A \) = Average soil loss (ton/ha/year)
\( R \) = Rainfall-runoff erosivity factor (MJ mm/ha/h/y)
\( K \) = Soil erodability factor (t ha h/ha/MJ/mm)
\( LS \) = Slope length (L) and slope gradient (S) factor
$C =$ Cropping management factor
$P =$ Supporting conservation practice factor

The equation is calculated using the Raster Calculator. All factors (R, K, LS, CP) are formatted in raster. In this case, we apply USLE because it is an appropriate model, wherein a tropical climate, the leading causes of erosion are rainfall and surface runoff [18].

2.2.5 Calculation of the critical land score

The level of land criticality assessment is influenced by 5 main factors, namely productivity, slope, erosion, rock outcrop, and land management (table 3). Calculation of land criticality level is done by multiplying the weights by scores on each parameter and adding them to get critical land scores [19] (Table 2).

| Protected Forest Area | Agricultural Cultivation Area | Protected Area outside Forest Area | Land Criticality |
|-----------------------|-------------------------------|------------------------------------|------------------|
| 120-180               | 115-200                       | 110-200                            | Heavy Critical   |
| 181-270               | 201-275                       | 201-275                            | Critical         |
| 271-360               | 276-350                       | 276-350                            | Rather Critical  |
| 361-450               | 351-425                       | 351-425                            | Potential Critical |
| 451-500               | 426-500                       | 426-500                            | Not Critical     |

Table 3. Criteria for scoring critical areas of agricultural cultivation areas

| No | Criteria (weight) | Class                    | Description          | Score |
|----|-------------------|--------------------------|----------------------|-------|
| 1  | Productivity (30) | Very high                | >80%                 | 5     |
|    |                   | High                     | 61-80%               | 4     |
|    |                   | Medium                   | 41-60%               | 3     |
|    |                   | Low                      | 21-40%               | 2     |
|    |                   | Very low                 | <20%                 | 1     |
| 2  | Slope (20)        | Flat                     | <8%                  | 5     |
|    |                   | Gently sloping           | 9-15%                | 4     |
|    |                   | Moderately steep         | 16-25%               | 3     |
|    |                   | Steep                    | 26-40%               | 2     |
|    |                   | Very steep               | >40%                 | 1     |
| 3  | Erosion (15)      | Light                    | < 60 ton/ha/yr       | 5     |
|    |                   | Medium                   | 60-180 ton/ha/yr     | 4     |
|    |                   | Heavy                    | 180-480 ton/ha/yr    | 3     |
|    |                   | Very heavy               | > 480 ton/ha/yr      | 2     |
| 4  | Rock Outcrop (5)  | Low                      | <10%                 | 5     |
|    |                   | Medium                   | 10-30%               | 3     |
|    |                   | High                     | >30%                 | 1     |
| 5  | Management (30)   | Good                     | Application for a conservation model | 5     |
|    |                   | Medium                   | Slight application for a conservation model | 3     |
|    |                   | Bad                      | -                     | 1     |
2.2.6 Correlation and regression analysis
Data obtained in the laboratory analysis will be carried out statistical analysis using the SPSS application to get the results of correlation and regression between soil fertility and the level of criticality of the land that has been previously calculated. The results of the analysis can be used as a reference in making recommendations for land management following land conditions.

3. Results and Discussion
3.1 Chemical Properties of Soil Dinoyo Sub Watershed

| SPL | Soil organic carbon (%) | Nitrogen (%) | Phosphor (ppm) | Potassium (me/100g) |
|-----|-------------------------|--------------|----------------|--------------------|
| 1   | 4.56                     | 0.18         | 11.49          | 0.12               |
| 2   | 2.36                     | 0.12         | 12.23          | 0.56               |
| 3   | 1.00                     | 0.14         | 24.03          | 0.52               |
| 4   | 2.29                     | 0.13         | 16.79          | 0.42               |
| 5   | 2.01                     | 0.13         | 25.02          | 0.37               |
| 6   | 3.65                     | 0.12         | 10.92          | 0.08               |
| 7   | 3.57                     | 0.13         | 21.32          | 0.12               |
| 8   | 3.36                     | 0.10         | 14.85          | 0.33               |
| 9   | 1.53                     | 0.11         | 11.97          | 0.51               |
| 10  | 1.46                     | 0.12         | 8.22           | 0.38               |
| 11  | 1.66                     | 0.09         | 48.04          | 0.23               |
| 12  | 1.66                     | 0.10         | 23.55          | 0.55               |
| 13  | 2.37                     | 0.09         | 53.54          | 0.39               |
| 14  | 1.72                     | 0.11         | 69.15          | 0.33               |
| 15  | 1.27                     | 0.10         | 85.73          | 0.47               |
| 16  | 1.81                     | 0.09         | 42.75          | 0.14               |
| 17  | 1.79                     | 0.11         | 16.32          | 0.07               |
| 18  | 1.45                     | 0.09         | 78.46          | 0.07               |

3.1.1 Soil organic carbon (SOC)
SOC percentage describes the content of organic matter in the soil. The analysis showed that the percentage of SOC in SPL 1 (4.56%) was the highest (Table 4). This is because SPL 1 is a forest area that is still under natural conditions. The lack of land management in this SPL makes the content of organic matter to be high. Land management in an ecosystem causes a decrease in organic carbon in the soil. The topsoil of the soil is disturbed by material displacement due to rainwater, even though this part contains most of the soil organic matter. SPL 3 (1%) with plantation land use has the lowest percentage of SOC. The intensity of tillage which is done without offset the provision of organic fertilizer makes the area of the plantation has a low organic material.

3.1.2 Nitrogen (N-total)
The highest nitrogen concentration was found in SPL 1 (0.18%) with forest land use (Table 4). The high content of organic matter affects the total N concentration in the soil because organic matter is one of the suppliers of nitrogen in the soil [20]. While the lowest N concentration was found in SPL 16 (0.09%) with the dominance of estate and agricultural land use. Intensive land use can reduce the concentration of element N in the soil, so it is necessary to add fertilizer to this land use.

3.1.3 Phosphor (P-available)
Plantation land use (SPL 15) has the highest phosphorus content (85.73 ppm) (Table 4). The utilization of plantation land to produce agricultural products must meet the nutrient needs of each plant. The addition of intense chemical fertilizers caused this SPL to have the highest phosphorus content. The
lowest phosphorus content (8.22ppm) is also found in plantation land use, the difference in P content in the two SPL is due to the slope, and caused the nutrients leaching. Although inorganic P content in soils is relatively high, it is often absorbed in insoluble and tightly bound forms. The concentration of Al in acidic soil pH and Ca in basic soil pH can bind the P element so that it cannot be absorbed by plants, so the need for mineralization so that the P element can be available [21].

3.1.4 Pottasium (K-available)
SPL 2 with forest land use has the highest K element content (0.56 me / 100g) (Table 4). The rate of immobilization and mineralization in land use is balanced so that the availability of element K in the soil can be maintained. Excessive absorption by plants can reduce the content of element K in the soil. SPL 17 with paddy fields land use has the lowest K element content (0.07 me / 100g). This is because paddy requires high K nutrients mainly in the generative phase, so that nutrients are directly absorbed by plants. Loss of element K in soil solution also occurs due to leaching, so there is a need for technical conservation in steep slopes and the addition of organic matter to increase soil colloids [22].

3.2 Erosion Hazard Level of Dinoyo Sub Watershed
Erosion is the process of transporting soil particles by rainwater and surface runoff and accumulates to a lower place [23]. Five factors affect the value of erosion, namely soil type, rainfall, slope and slope length, and vegetation management. The higher the value of each factor, the greater the value of erosion.

Soil type will affect the texture, structure, and content of organic matter. Different soil characteristics will affect the amount of soil loss through erosion [24]. Raindrops will cause damage to soil aggregates so that soil particles are easily eroded. High rainfall intensity also causes high runoff rates and transportation of soil particles to more distant places [25]. Steeper and longer slopes also increase erosion [23]. Vegetation management will also affect erosion, the selection of vegetation according to other land characteristics will be able to reduce the value of erosion.

The Dinoyo watershed consists of protected forest areas and agricultural cultivation areas. The upstream Dinoyo watershed is a forest area, while the middle area is a coffee plantation and downstream areas are settlements, fields, and rice fields. The results of the erosion calculation are shown in Figure 2.

Based on the calculation results, the majority of land in the Dinoyo sub-watershed has very heavy erosion. Land that has very heavy erosion reaches 2093 Ha, while land that has very low to moderate erosion is only 1407.53 ha (Table 5). Land that is categorized as heavy erosion is 6.12 ha, if the condition is left then the land will turn into very heavy erosion. The upstream area of the Dinoyo sub-watershed
using forest land has very low erosion. While the central region with land use as a coffee plantation has very heavy erosion. Some downstream areas are also categorized as very heavy erosion, this is because the downstream area is widely used as a residential area.

| Erosion (ton/ha/yr) | Wide Ha | % | Erosion hazard level |
|---------------------|---------|---|----------------------|
| 0-15                | 1,406   | 40.094 | Very light           |
| 15-60               | 0.09    | 0.003 | Light                |
| 60-180              | 1.44    | 0.041 | Medium               |
| 180-480             | 6.12    | 0.175 | Heavy                |
| >480                | 2,093   | 59.687 | Very Heavy           |
| Total               | 3,506   | 100  |                      |

3.3 Level of land criticality of Dinoyo Sub Watershed

Critical land is land that is physically unable to support its designation either as a crop production or as a conservation land [26]. In addition to erosion, four factors affect critical land, namely slope, land productivity, land management, and rock outcrops. The following are the results of scoring the four factors:

![Figure 4. Map of land management Dinoyo Sub-watershed.](image)

![Figure 5. Map of slope Dinoyo Sub-watershed.](image)

![Figure 6. Map of rock outcrop Dinoyo Sub-watershed.](image)

![Figure 7. Map of productivity Dinoyo Sub-watershed](image)

The Dinoyo watershed consists of three parts, namely upstream, middle and downstream. The upstream area of the Dinoyo Sub-watershed has good land management and productivity (fig. 4 and 7), but the
upstream area has a very steep slope (fig. 5). Rock outcrops in the upstream region are also categorized as moderate (fig. 6). This is because the upstream area is a protected forest area so that the community cannot freely utilize the forest.

The middle area is a coffee plantation area with moderate to very steep slopes (fig. 5) and rock outcrops included in the high category (fig. 6). Central regions have moderate management and productivity (fig. 4 and 7). Management in this plantation area must be improved to minimize the steep slope and high rock outcrops, which in turn will increase land productivity.

Downstream areas are areas that are used as residential areas, rice fields, and fields. The physical condition of this area is suitable for agriculture due to the gentle slope (fig. 5) and low rock outcrops (fig 6). However, some points in downstream areas have poor management and productivity (fig. 4 and 7). Areas that have poor management and productivity are areas that are used as settlements.

The results of the assessment of erosion factors, management, rock outcrops, productivity, and the slope will affect the criticality of land. The worse the score of each factor, the land is included in the critical category. Based on the results of the critical land assessment, Dinoyo Sub-watershed has two categories namely heavy critical and rather critical (fig. 8). The upstream area belongs to the rather critical category, while the middle area which is a plantation area belongs to the heavy critical category.

![Map of land criticality Dinoyo Sub-watershed.](image)

**Figure 8.** Map of land criticality Dinoyo Sub-watershed.

| Land Critical Score | Wide | Land Critical |
|---------------------|------|---------------|
| 115-200             | 2,333.88 | Heavy critical |
| 201-275             | -    | Critical      |
| 276-350             | 1,172.34 | Rather critical |
| 351-425             | -    | Potential critical |
| 426-500             | -    | Not critical  |

Table 6 shows the Dinoyo sub-watershed consists of two critical land categories namely heavy critical and rather critical. There are 2333.88 hectares which are categorized as heavy critical, and the remaining 1172.34 hectares are categorized as rather critical. Areas with heavy critical categories must be immediately repaired to minimize the environmental impacts caused. Areas with a rather critical category also need to be improved so that conditions do not continue to decline to the heavy critical category.
The upstream area of the Dinoyo watershed in the form of protected forest belongs to the rather critical category. This is because the upstream Dinoyo Sub-watershed has experienced flash floods in 2009, so it takes longer to restore conditions to normal. Forest conservation efforts need to be improved continuously to increase their carrying capacity on the environment.

The middle area is a coffee plantation area categorized as heavy critical. The plantation area in the Dinoyo Sub-watershed are belong to individual plantation and government plantation. Land management on these plantations only focused on the coffee production and ignored the sustainability aspect. Poor plantation management causes erosion and nutrient loss. This causes the fertilizer that applied to the soil was unable to increase productivity due to erosion.

Figure 4 shows that the slope of coffee plantation areas is steep (25-40%) to very steep (> 40%). This area should not be planted with plantation crops. Areas with very steep slopes should be planted with annual plants that have taproots to prevent erosion [27]. Plantation practices in the highlands have an impact on soil sensitivity to erosion and landslides. Mismanagement will cause biophysical damage, such as degradation of soil fertility and water availability.

Shade plants are one of the conservation techniques that need to be considered in managing plantations. This is because the coffee plant does not require full sunlight and the roots of the coffee plant are not strong enough so that the soil is easily eroded [28]. Shade plants can reduce erosion and minimize the loss of nutrients that are given. Decreasing the value of erosion and increasing productivity will reduce the occurrence of critical land.

In addition to regulating plants, other factors that need to be improved are fertilization and pruning. Based on the interview results, several plantation areas are only given chemical fertilizer. The application of chemical fertilizers can cause soil compaction and with steep slope conditions, the fertilizer will be easy leaching [11]. Improper fertilization will affect production. Pruning coffee plants is done irregularly, this makes the production results not optimal. Inadequate coffee production makes productivity low so this area is included in the very critical category.

3.4 Relationship between Land Criticality and Soil Chemical Properties of Dinoyo Sub Watershed

The estimated C-Organic regression of land criticality is 0.01 at a significance level of 5% (table 7). This shows the influence of C-Org on land criticality because the regression results are still below the level of significance. The low content of organic matter in the soil will have an impact on the essential nutrient content in the soil. Organic matter is one of the organic colloids that can absorb cations before they are absorbed by plants [29]. Increased soil colloids will be able to increase the availability of plant nutrients. Organic material is also able to prevent erosion, thereby reducing the occurrence of critical land.

| Model   | Unstandardized Coefficients | Std. Coef | t     | Sig.  |
|---------|-----------------------------|-----------|-------|-------|
| (Constant) | 1.793 | .158 | 11,319 | .000 |
| C_Org   | -.159 | .066 | -.317 | -.2,414 | .019 |

| Model   | Unstandardized Coefficients | Std. Coef | t     | Sig.  |
|---------|-----------------------------|-----------|-------|-------|
| (Constant) | 2,034 | .353 | 5,767 | .000 |
| Nitrogen | -5.15 | 3,025 | -2.3 | -1,702 | .095 |

The result of the regression analysis between nitrogen and land criticality is 0.09; these results are more than the significance level of 5% (table 8). This shows that nitrogen does not affect the criticality of the land. Nitrogen is one of the essential elements for plants, one of which is a nitrogen source of
organic matter. Organic matter influences soil criticality, but nitrogen does not directly influence land criticality. Nitrogen will affect plant growth, especially in the vegetative phase [30].

**Table 9.** Regression analysis between phosphor and land criticality

| Model       | Unstandardized Coefficients | Std. Coef | t  | Sig. |
|-------------|-----------------------------|-----------|----|------|
|             | B  | Std. Error | Beta |     |     |
| (Constant)  | 1,428 | .114 |     | 12,578 | .000 |
| 1            | Phosphor | .001 | .003 | .025 | 18 | .858 |

**Table 10.** Regression analysis between potassium and land criticality

| Model       | Unstandardized Coefficients | Std. Coef | t  | Sig. |
|-------------|-----------------------------|-----------|----|------|
|             | B  | Std. Error | Beta |     |     |
| (Constant)  | 1,149 | .132 |     | 8,707 | .000 |
| 1            | Potassium | .944 | .367 | .336 | 2,572 | .013 |

The estimated regression results of phosphorus (P) on land criticality is 0.85 which is greater than the significance level of 5%, this shows that phosphorus does not affect land criticality (table 9). Phosphor nutrient is one of the essential nutrients for plants, so its function cannot be replaced by other elements for plants. However, this element does not affect the criticality of the land because the mineralization of this element comes from rocks, not from organic matter. Another factor is also due to the availability of nutrients in the Dinoyo sub-watershed is relatively low. This nutrient has an indirect effect on crop productivity, increasing productivity will reduce the risk of critical land.

The results of the estimation of potassium regression (K) on land criticality are 0.01 which is lower than the significance level of 5% (table 10). This shows the influence of element K on land criticality. Element K influences land criticality because this element is an essential nutrient needed by plants so that it will affect the productivity of a land. Based on the results of the laboratory analysis, the availability in the Dinoyo sub-watershed is relatively high (Table 4).

4. Conclusion

Dinoyo sub-watershed consists of upstream, middle and downstream areas. The upstream has high nutrient availability, low erosion rates, and is quite critical. This is because the upstream part is a protected forest so that the condition is still maintained. The middle part is the coffee plantations area with low nutrient availability due to high erosion and classified as very critical land. Improved plantation management is needed to increase its carrying capacity on the environment. Downstream is part of fields, rice fields, and settlements that on average have low nutrient availability, high erosion, and criticality of rather critical land. Correlation and regression results show that organic matter is the most influential factor in increasing critical land. This is because low organic matter indicates high erosion and nutrient leaching, which can affect soil quality and productivity.

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