The Impact of slope steepness and land use type on soil properties in Cirandu Sub-Sub Catchment, Citarum Watershed

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Abstract. The research was conducted to investigate the relationship between topography (slope steepness) and land use on soil physical properties. This research was conducted at Cirandu sub-catchment, Citarik Catchment Area, Citarik Sub Watershed, Upper Citarum Watershed, West Java. The study was carried out using a physiographic free survey method, which is a survey based on land physiographic appearance, and soil sampling was carried out into transect on the similarity slope without calculating the point of observation range. Soil sampling was carried onto three classes of slope and three land use type. The result of the research showed that there are no effect of slope steepness and landuse on organic matter, hydraulic conductivity and erodibility. The highest erodibility value was found on the forest with 8-15% slope.

1. Introduction
Fulfilling human necessity due to population growth results destruction of natural resources such as watershed instability. For example, erosion emerges due to improper land use management. Land use change shifts the actual erosion of an area due to the change of cover crop on the soil surface. The effect of plants on erosion is determined by the type of plant, plant density, distribution, height and the direction of strip cropping [1]. The effect of plant species on erosion is determined by the canopy and its roots, while the density and distribution of plants indicate the protected soil surface area from rain splash.

Moreover, steep slope is assumed as a trigger of erosion [2]. The steep slope will increase the number and speed of runoff so that erosion will be accelerated due to more transported and dissolved materials [3]. Steeper slope will enhance the flow resulting a bigger power and amount of water to transport the soil. Increment of erosion on steep slopes is the result of the increment of surface runoff [4] and also the reason for the decline of infiltration [6]. Generally, slope class of 18-15%, 15-25%, 25-40% are assumed as a vulnerable areas for erosion. Hence, these classes must have special attention and treatment. The condition of a watershed must be precisely known to evaluate and mitigate the damage. Cirandu sub-catchment in Citarik catchment, which is located in the upstream of the Citarum watershed needs more attention since this watershed is very important due to its ability as water and electricity supply for the people in Java.
The percentage of the forest is noted only less than 26.4% of the total watershed area [7]. Thus, high erosion (486,193 tons/ha/yr) was found in the watershed. Biophysical destruction due to erosion can be seen from the changes in hydraulic conductivity, porosity and organic matter [8]. The detached soil particle will close soils pores, and eventually, change the hydraulic conductivity and porosity.

2. Materials and Methods
The research was carried out in the Cirandu sub-catchment, Citarik catchment, Upper Citarum watershed with an area 53,500 Ha (Figure 1). The type of soil in the study area is Inceptisols. The condition of vegetation in the Citarik Sub-watershed is distinguished between plants in the forest area and plants outside the forest area. Vegetation that is outside the forest area consists of seasonal plant species including cassava, beans, chili and secondary crops. Land use type can be seen from Figure 2.

![Figure 1. The Location of Soil sampling](image)
Figure 2. Land use type in the study area

The study area has a tropical climate, affected by monsoons, which can be distinguished between the rainy and dry season. The rainy season occurs from November to April and the dry season from May to October. Annual rainfall ranged from 1,521 to 2,087 mm. The number of rainy days in a year ranged from 104 to 180 days. The average wet month is noted 6 to 12 months. The average annual temperature is 22°C to 24°C with humidity ranging from 68% to 83%.

This research was conducted in a free physiographic survey [8]. It is a survey method based on the appearance of the land physiographic shape and random sampling of the land without taking into
account the distance between the observation points. Observations were made based on land unit classifications, namely slope class, climate and practice management [9].

Soil survey was conducted to obtain the information of slope steepness and classified as a percentage (%). Observations and samples were collected in the different slopes and land uses (Table 1). Three slopes are consisted of moderate (8-15%), moderately steep (16-25%) and steep (26-40%). The observed land use classes are consisted of forests, mixed plantation and dry fields. The observed land uses were conducted on top, middle and bottom positions. The position of the slope was determined by measuring the length of slope (based on the map) and divided by three, namely the upper, middle, and lower slopes.

The combination of the two independent variables was combined with four times of replication, results 36 points (Figure 1). Disturbed and undisturbed soil sampling was collected to determine the soil physical properties, such as organic matter (OM), hydraulic conductivity and porosity.

### Table 1 Independent Variable

| Independent Variable | Class                | Repetition |
|----------------------|----------------------|------------|
| Steepness            | Moderate (8-15 %)    | (L₁)       |
|                      | Moderately steep (16-25 %) | (L₂)     |
|                      | Steep (26-40 %)      | (L₃)       |
| Land use             | Forest               | (P₆)       |
|                      | Mix plantation       | (P₄)       |
|                      | Dry cultivation area | (P₅)       |

Determination of organic material used the Walkley and Black method. The measurements of soil hydraulic conductivity in the laboratory were carried out based on Darcy's law. Soil erodibility data was calculated using [10] method, modified by [11] with five soil properties variables. The interaction of these variables is explained in the following equation:

\[
100K = 2,713M^{1.14}(10^{-4})(12 – a) + 3,25(b – 2) + 2,5(c – 3)
\]

where,  
- K : Soil erodibility factor  
- M : Soil texture class  
- a : percent of OM  
- b : Soil structure  
- c : hydraulic conductivity

The results of the erodibility calculation are classified based on the hydraulic conductivity classification in Indonesia according to [12] as presented in Table 2.

### Table 2. Soil Erodibility classes in Indonesia

| Class | K value | Erodibility Class    |
|-------|---------|----------------------|
| 1     | 0.1     | Very low             |
| 2     | 0.10-0.15 | Low                |
| 3     | 0.15-0.20 | Moderately low   |
| 4     | 0.20-0.25 | Moderate            |
| 5     | 0.25-0.30 | Moderately high    |
| 6     | 0.30-0.35 | High               |
| 7     | > 0.35  | Very high           |
3. Results and Discussions

3.1. Effect of Land Use and Slope Classes on Organic Matter Content

Based on the analysis of variance and Tukey, the combination effect of slope class and land use on OM was not found (Table 3).

| Code  | Treatment               | C- organic (%) |
|-------|-------------------------|-----------------|
| PdL1  | Forest (moderate)       | 13.07 a         |
| PdL2  | Forest (moderately steep)| 12.14 a        |
| PdL3  | Forest (steep)          | 11.58 a         |
| PnL1  | Mix plantation (moderate)| 11.17 a        |
| PnL2  | Mix plantation (moderately steep)| 11.88 a       |
| PnL3  | Mix plantation (steep)  | 11.51 a         |
| PdL1  | Dry cultivation (moderate)| 8.80 a        |
| PdL2  | Dry cultivation (moderately steep)| 11.35 a       |
| PdL3  | Dry cultivation (steep) | 11.64 a         |

Remark: All numbers which are followed by the same letter are not significantly different based on 5% level of confidence of variance analysis.

The percentage of OM ranged from 8 to 13%. Slope class and land use do not affect significantly on OM content. Beyond that, a clear decline of OM can be identified on moderately steep and steep slopes. This could have resulted from erosion. As generally known, erosion brings soil fractions faster and further from its original place (Morgan, 1979), including OM. Moreover, the bond between OM and water is very strong, so it is very easy to be carried by the water.

OM loss is a disadvantage for the soil. Soil OM plays a role as a cemented agent between soil particles to form soil aggregates [14]. In addition, OM able to absorb and retain a high amount of water for two to three times its weight [1]. These characters are an advantage for agriculture and conservation because OM will prohibit runoff and increase infiltration [15].

3.2. Effect of Slope Class and Land Use on Soil Hydraulic Conductivity

Treatment PdL1 and PnL1 give the highest impact, as pointed by the notation (Table 4). Meanwhile, the moderately steep and steep slope in all vegetation gives a lower hydraulic conductivity. The decline of soil hydraulic conductivity value is linear with the slope steepness. The highest hydraulic conductivity is noted 1.55 mm min⁻¹ for forest and moderate slope. This value is higher compared to the hydraulic conductivity on the lower moderately steep slope (1.37 mm min⁻¹), the steep slope (1.31 mm min⁻¹), steep slope (1.30 mm min⁻¹), and steep slope (1.13 mm min⁻¹).

The high value of hydraulic conductivity in the forest (moderately steep) and mix plantation (moderately steep) is easy to understand. In the erosion calculation, forest is vegetation with a very low C factor index due to the maximum canopy cover and maximum microenvironment. Forest canopy is able to intercept rain splash onto the soil surface. Moreover, forest plays a role in providing organic material through the decomposition of the dead plant [16]. Organic material creates a the crumb structure, high porosity, and high absorption water. Crumb structure allows more water amount into the soil vertically because crumb structure has a larger macropore than the micropore. The high porosity of high OM soil is caused by the movement of macrofauna. Their life is supported by the presence of organic material as their food. In addition, the roots and stems of plants on the surface of the soil have a larger areas and width compared with other vegetation. Those conditions interrupt
runoff, at the same time water has more time to infiltrate. These four reasons are the reason why hydraulic conductivity is high on the forested areas.

### Table 4. Effect of Slope Class and Land Use on Soil Hydraulic conductivity

| Code | Treatment                          | Hydraulic conductivity (mm min⁻¹) |
|------|------------------------------------|-----------------------------------|
| P₇L₁ | Forest (moderate)                  | 1.55 e                            |
| P₇L₂ | Forest (moderately steep)          | 1.48 de                           |
| P₇L₃ | Forest (steep)                     | 1.31 b                            |
| P₈L₁ | Mix plantation (moderate)          | 1.55 e                            |
| P₈L₂ | Mix plantation (moderately steep)  | 1.46 cde                          |
| P₈L₃ | Mix plantation (steep)             | 1.30 b                            |
| P₉L₁ | Dry cultivation (moderate)         | 1.49 de                           |
| P₉L₂ | Dry cultivation (moderately steep) | 1.37 bc                           |
| P₉L₃ | Dry cultivation (steep)            | 1.13 a                            |

Remark: All numbers which are followed by the same letter are not significantly different based on a 5% level of confidence of variance analysis.

Human activities and sometimes even using heavy equipment at a higher slope position of the study are commonly found. This happens because the upper slope plays as easier entrance to a certain location. Permeability is increasing due to the practice of land management, human activities, and the use of heavy equipment [17]. The presence of heavy equipment causes compaction and creates low porosity due to the reduction in macro and micropores. Finally, it creates lower soil hydraulic conductivity.

### 3.3. Effect of Slope Class and Land Use on Land Erodibility

The combination results between slope class and land use type on soil erodibility is presented in Table 7. The combination of moderate slope with forest vegetation and dry cultivation has almost the same value and considered as the highest soil erodibility value statistically. Beyond that, another combination has a non-significant effect on erodibility. Combined moderate slope with all land use type result a higher erodibility value compared to the combined middle and lower slope classes. This condition cannot be explained due to insufficient data.

### Table 5. Effect of Slope Class and Land Use on Soil Erodibility

| Code | Treatment                          | Erodibility  |
|------|------------------------------------|--------------|
| P₇L₁ | Forest (moderate)                  | 0.984 b      |
| P₇L₂ | Forest (moderately steep)          | 0.018 a      |
| P₇L₃ | Forest (steep)                     | 0.067 ab     |
| P₈L₁ | Mix plantation (moderate)          | 0.980 b      |
| P₈L₂ | Mix plantation (moderately steep)  | 0.012 a      |
| P₈L₃ | Mix plantation (steep)             | 0.055 a      |
| P₉L₁ | Dry cultivation (moderate)         | 0.981 b      |
| P₉L₂ | Dry cultivation (moderately steep) | 0.061 ab     |
| P₉L₃ | Dry cultivation (steep)            | 0.055 a      |

Remark: Numbers followed by the same letter are not significantly different based on the Tukey Test at the 5% level.
It is widely known that the value of erodibility will increase linearly with increasing slope. But the anomaly is possibly existed due to external factor such as differences in plant density at the study site. In some locations, the distance of the plants is denser than the distance of other plants. This will impact on changes in the index value C index. Although in the same crop, the index value of the C factor will be different if the plants are planted in a different. This difference will directly affect the amount of erosion. In ideal conditions, the calculation of erosion and its supporting factors including erodibility calculation must include the proportions impact of different plants so that it will produce logic and precise calculation.

The calculation of the erodibility value in this study is related to the hydraulic conductivity and content of OM. The moderate slopes show high hydraulic conductivity values. High hydraulic conductivity results a low erosion rate. On the opposite, low hydraulic conductivity causes high erodibility. Low hydraulic conductivity creates a lower infiltration. Non-infiltrated water will become a surface runoff that creates higher erosion and cause degradation of soil properties, especially the physical properties of the soil [1].

4. Conclusions
The slope and land use do not affect OM, meanwhile, it affects the hydraulic conductivity and erodibility. The combination if forest and moderate slope results a high soil erodibility value. The implementation of conservation techniques must be considered because it greatly influences the erosion in the study area.

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