Soil Erosion Prediction of Different Agroforestry Land System at the Upper Citarum Watershed using MUSLE Model

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Abstract. Land conditions in the upper Citarum watershed have been increasingly critical in recent times, causing various problems, especially the high erosion that is considered one of the factors causing river sedimentation and triggering flood. Agroforestry has provided a positive impact on the soil conservation aspect. The dense and critical land in the Upper Citarum watershed has been converted to agroforestry in the last decades. This study aims to estimate the rate of soil erosion of different agroforestry land systems at the Upper Citarum watershed using the MUSLE model. The results show that the surface runoff and soil erosion in forest-based agroforestry systems with intercropping patterns is lower than in farm-based agroforestry.

1. Introduction
The rapid land-use changes in the upper Citarum watershed have resulted in increased soil erosion [1]. Soil erosion causes flooding, drought, land degradation, declining soil productivity, and decreasing water quality [2,3]. The watershed recovery acceleration in the Upper Citarum Watershed through the forest and land rehabilitation program (agroforestry land system) has been carried out since 2015 [4].

The agroforestry combines the functions of forest trees and crops as a form of acculturation of environment and land system so that besides being able to contribute economically, it also has a positive impact on soil conservation [5–7], reduce soil erosion [8] improve soil quality [9,10] and soil productivity [9].

In the agroforestry system, the forest-based agroforestry and farm-based agroforestry will provide different soil, water, and plant cycles, especially soil erosion. Farm-based agroforestry with the main product of agricultural crops and forestry components is a supporting element for increasing productivity and the sustainability of this system. Meanwhile, forest-based agroforestry is more dominant for the forest/wood products.

The MUSLE model does not use the rain energy factor as the cause of erosion, but instead uses the surface runoff factor. Therefore, the MUSLE model does not require a sediment delivery ratio (SDR) factor because the surface runoff factor represents the energy used for the demolition and transport of sediment. The advantage of this method is that it measures erosion on small plots, is widely used worldwide, is relatively simple, and the input parameters required are relatively few compared to other erosion models.
This study aimed to determine the surface runoff and soil erosion between forest and farm-based agroforestry land systems using MUSLE Model.

2. Materials and Methods
The study was carried out at Mandalahaji village, Bandung sub-district, West Java province, Indonesia and was part of the upper Citarum watershed, with elevation ranging from 960 to 970 m a.s.l. The study was located at three specific agroforestry land system sites, with each slope at 32%. The three locations of the agroforestry systems consist of Gmelina arborea monoculture plantations on-site 1 as forest-based agroforestry, an intercropping of Coffea arabica + horticulture on-site 2 as farm-based agroforestry, and an intercropping of Gmelina arborea + Coffea arabica on-site 3 as forest-based agroforestry (Fig. 1).

![Map of West Java province, Indonesia](image)

**Figure 1.** Three research site location in Mandahaji village

The analysis was performed with erosion prediction modeling using the Modified Universal Soil Loss Equation (MUSLE) model. The MUSLE model analysis was used to determine the erosion level on the three sites of the agroforestry system with equation 1 [11]. Surface runoff ($Q_{surf}$) can be estimated with equation 2. Surface runoff is calculated by the Curve Number method (SCS-CN) [12–14].

\[
Y = 11.8 (Q_{surf} q_{peak} A_{area})^{0.56} \times K \times L \times S \times C \times P
\] (1)

\[
Q_{surf} = \frac{(R+0.2S)^2}{(R+0.8S)}
\] (2)

\[
S = 25.4 \left( \frac{1000}{CN} - 10 \right)
\] (3)
where \( Y \) (soil loss in metric ton), \( Q_{surf} \) (surface runoff in mm), \( q_{peak} \) (peak runoff in \( m^3 \) second\(^{-1}\)), \( A \) (area in ha), \( K \) (soil erodibility factor), \( LS \) (length and slope factor), \( CP \) (crop management, soil conservation factor), \( R \) (daily rainfall in mm), \( i \) (maximum rainfall intensity in mm/hour), \( S \) (potential maximum retention in mm), \( C \) (runoff coefficient), \( M \) (particle size parameter), \( a \) (organic matter in \%), \( b \) (soil structure class), and \( c \) (permeability class).

The peak runoff rate \( q_{peak} \) using the rational method (equation 4) [15], topographic factors (equation 5) and erodibility index (equation 6). The runoff coefficient \( C_{kl} \) uses in the Hassing method [16] is obtained by combining the topographic factor runoff coefficient \( C_{kl-t} \), soil factor \( C_{kl-s} \), and cover vegetation \( C_{kl-v} \).

The relationship between surface runoff and soil erosion variables using the Pearson correlation was tested to determine the correlation coefficient \( r \), which was further tested with a regression. Research data were processed using Microsoft Excel and SPSS Statistics 22 software.

### 3. Results and Discussions

Property data for soil erosion modeling is presented in Table 1. Table 1 shows the similarity of data in R, LS, and \( P_{crop} \) values, which it shows the geographical similarity in the occurrence of rain, slope topographic conditions (22 m length and 32% slope), and the conservation effort index \( (P_{crop}) \) of the research sites.

| Agroforestry system pattern | CN \([12]\) | \( C_{lp} \)[16] | \( R \) | \( K_{soil} \) | \( LS \) | \( C_{crop} \) [18] | \( P_{crop} \) [18] |
|-----------------------------|------------|---------------|------|----------------|------|----------------|------------|
| Site 1                      | 83.0       | 0.53          | 354.7| 0.116-0.133    | 8.7  | 0.825          | 0.14       |
| Site 2                      | 79.0       | 0.46          | 354.7| 0.075-0.106    | 8.7  | 0.160          | 0.14       |
| Site 3                      | 77.0       | 0.46          | 354.7| 0.071-0.095    | 8.7  | 0.190          | 0.14       |

Source: * own calculation

The CN values in Table 1 for all study sites included the type D soil hydrological group category [12,14] characterized by infiltration rates of 0-1 mm/hour and clay texture. Site 1 with poor drainage category has a CN value of 83.0. Site 2 with moderate drainage conditions has a CN value of 79.0, and site 3 with good drainage conditions has a CN value of 77.0. The K index of each study plot shows varying values where site 1 has a K index higher than site 2 and 3 (Table 1). The soil erodibility index \( (K_{soil}) \) varies based on laboratory results (very fine sand fraction, dust, sand fraction, organic matter, soil structure, and permeability). Plant index \( (C_{crop}) \) is determined based on vegetation distribution in each site [17]. The conservation effort index \( (P_{crop}) \) has the same bench terrace with a \( P_{crop} \) of 0.14 [18] for all sites.
Table 2. Average of surface runoff and soil erosion

| Agroforestry system pattern | Surface Runoff ($Q_{surf}$) (mm) | Soil Erosion (Y) (Ton) |
|----------------------------|----------------------------------|------------------------|
| Site 1                     | 0.62                             | 14.95                  |
| Site 2                     | 0.42                             | 1.47                   |
| Site 3                     | 0.36                             | 1.29                   |

Source: own calculation

The results of surface runoff and eroded soil prediction are shown in Table 2. Site 3 gives the smallest surface runoff (0.36 mm) and soil erosion (1.29 tons) yield compared to other sites. Site 1 produced the largest surface runoff (0.62 mm) and soil erosion (14.95 tons) yield. Site 3, with a K index range between 0.071-0.095, gives smaller surface runoff and soil erosion than site 1 and site 2.

Site 1 has a high surface runoff and erosion because although it has a coffee vegetation land cover, it tends to be in the farm-based land category. The higher CN values and runoff coefficients cause high surface runoff and amount of soil eroded on-site 1 than site 2 and 3. Forest-based agroforestry in site 2 and 3 gives the lowest eroded soil. There is a positive correlation between the CN index with surface runoff ($r = 0.994$) and soil erosion yield ($r = 0.95$) as shown in Figure 2 with coefficient determination ($R^2$) for surface runoff and soil erosion each 0.99 and 0.88. The lower CN index causes higher infiltration and decreased surface runoff and soil erosion. The occurs of shrubs, litter, and vegetation in sites 2 and 3 will reduce surface runoff and soil erosion. The combination of undergrowth and litter increases the infiltration capacity and reduces surface runoff [19]. In Figure 2a, the amount of data is only 3 data that reflect the Qsurf value in 3 research sites, while in Figure 2b, the data on soil erosion values are more varied because of variations in the erodibility index of each site (27 data on erodibility index variations).

![Figure 2. Relationship between surface runoff (a) and soil erosion (b) with CN Index (Source: own elaboration)](image-url)
There is a positive correlation between the erodibility index with surface runoff and soil erosion yield, as shown in Figure 3. The erodibility factor indicates the ease of soil erosion, where the higher the value, the greater the level of erosion. Erodibility factor is one of the factors that have a major influence on soil erosion [20].

![Diagram](image)

**Figure 3.** Relationship between surface runoff (a) and soil erosion (b) with an erodibility index

The soil erosion prediction results in this study indicate that the forest-based agroforestry (intercropping of *Gmelina arborea* + *Coffea arabica*) can reduce soil erosion than in farm-based agroforestry land system. This is due to the low CN and erodibility index in forest-based agroforestry compared to farm-based agroforestry. Coffee-based agroforestry can reduce erosion below the permissible level of erosion [21].

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