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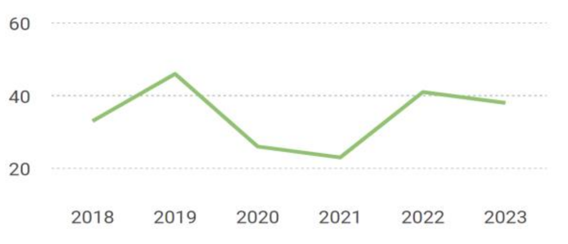

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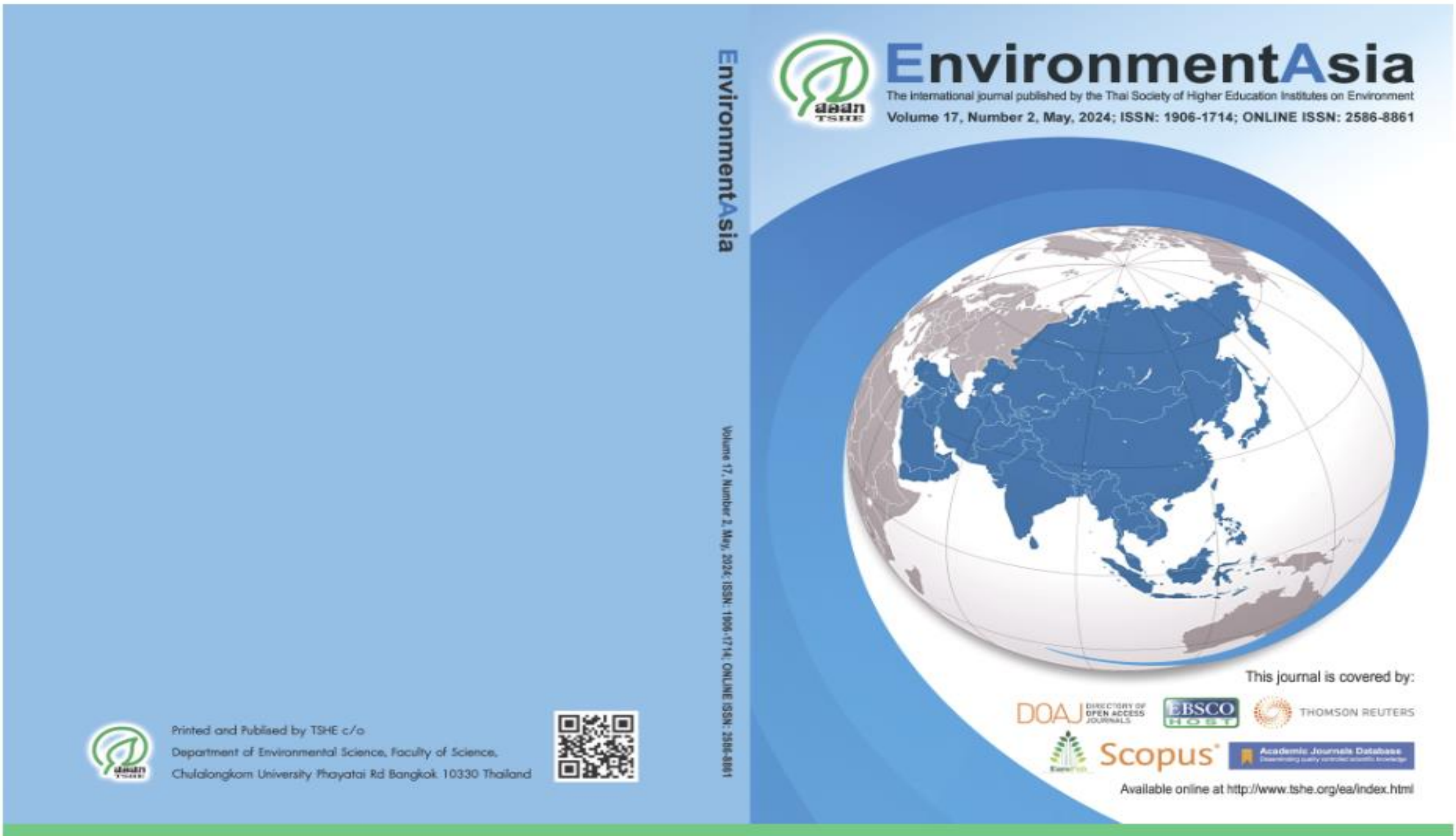
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Coffee Agroforestry for Soil Erosion Control in the Upstream of Ciliwung Watershed, West Java, Indonesia

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Abstract

The deteriorating condition of the upstream of Ciliwung Watershed exacerbated soil erosion and increasing flood risk in the downstream area, including DKI Jakarta, the capital city of Indonesia. Coffee holds a significant economic role in Indonesia and coffee agroforestry demonstrated effectiveness in erosion reduction. This study aims to examine the benefit of coffee agroforestry to control soil erosion through analyzing the influence of soil properties and vegetation composition. The study was conducted in four hamlets, namely Cibulao, Cikoneng, Rawa Gede, and Cisuren. Soil erosion was measured from Universal Soil Loss Equation calculation, while vegetation was measured from Shannon diversity index and importance value. The results showed that the erosion rates in all four study areas are below tolerated erosion rates. The highest erosion rate was found in Cikoneng (14.76 ton/ha/year) and the lowest is found in Cisuren (9.29 ton/ha/year). Cisuren has high slope steepness, highest organic matter content, and lowest Shannon diversity index. Cikoneng shows neither distinctive soil properties nor vegetation composition. Coffee agroforestry seems to keep the soil erosion rate under control. However, soil erosion rate is not solely dependent on individual factors, such as soil properties or vegetation cover, but rather on the combination of these elements.

Keywords: Agroforestry; Coffee plantation; Soil erosion; Upstream watershed

1. Introduction

The Ciliwung watershed covers a large area, including the upstream and midstream areas in West Java and the downstream area in DKI Jakarta. The natural pattern and topography of the Ciliwung watershed shape the stream's characteristics, promoting the rapid flow of water downhill. The watershed exhibits a pattern reminiscent of leaf twigs, with tributaries converging at sharp angles into the main river (Ali *et al.,* 2016; Anggraheni *et al.,* 2018). West Java has high-intensity rainfall of about 3500 mm per year (BPS, 2022). The down ward incline, combined with the region's intense rainfall, exacerbated soil erosion upstream and increased the flood risks downstream. In addition, rapid urbanization, and land conversion of natural areas into urban landscapes have altered the hydrological characteristics of the Ciliwung watershed, increasing the risk of soil erosion and flooding even further. The flood volume and flood area in Ciliwung Watershed are predicted to increase 101.7% and 91%, respectively, in 2030 (Farid *et al.,* 2022).

The upstream area of the Ciliwung Watershed plays a vital role as a hydrological environmental regulator for upstream, midstream, and downstream areas.

Any alterations to the upstream components would have widespread implications for the entire watershed, particularly for the downstream area (Ahmed *et al.,* 2019). Unfortunately, the condition of the upstream Ciliwung Watershed is deteriorating, and it falls into the category of degraded land with evident changes in forest cover, attributed to human activity, alterations in soil composition, and climatic factors (Fitri *et al.,* 2020; Wijitkosum, 2021). The main reason is due to land use conversion, specifically the transition from vegetated areas to built-up areas (Hasibuan *et al.,* 2022; Robo *et al.,* 2019; D. Wang *et al.,* 2012), causing an increase in surface runoff (Salim *et al.,* 2019; Sulaeman *et al.,* 2014), that leads to flood hazard in the downstream area. DKI Jakarta, located downstream, faces a major threat due to the degradation of the upstream Ciliwung Watershed. As the capital city and the business center in Indonesia, the potential impacts are massive as it will significantly disadvantage a large population. Therefore, conserving the upstream area becomes even more crucial.

Agroforestry can be perceived as a form of agricultural landscape that integrates trees within croplands and pasturelands, providing benefits in climate change mitigation programs while simultaneously yielding crop products (Getnet *et al.,* 2023). Coffee holds a significant economic role in Indonesia, contributing substantially to the country's agricultural sector and providing livelihoods for numerous farmers. Monoculture coffee production is known to be vulnerable to soil erosion (Cerretelli *et al.,* 2023), but agroforestry systems of coffee and mixed shade trees have demonstrated effectiveness in erosion reduction through the canopy cover they provide and their role in contributing to the litter layer (Blanco Sepúlveda & Aguilar Carrillo, 2015).

Research about ecosystem services of coffee agroforestry keep increasing over the years (De Leijster *et al.,* 2021; Mokondoko *et al.,* 2022; Notaro *et al.,* 2022), and some of them focuses on their benefit in relation to soil erosion control (Blanco Sepúlveda & Aguilar Carrillo, 2015; Meylan *et al.,* 2013; Ramos Scharrón, 2023). Most of coffee agroforestry system related studies are conducted in Central and South America, and very little is known about the coffee agroforestry in Indonesia, specifically in the Upstream of Ciliwung Watershed, despite its big potential to mitigate the worsening flood hazard in DKI Jakarta. To optimize the effectiveness of coffee agroforestry in soil erosion control, it is crucial to understand the primary factors influencing soil erodibility. A study in Northern Nicaragua found that soil erosion is mainly determined by the litter layer and slope gradient (Blanco Sepúlveda & Aguilar Carrillo, 2015). Meanwhile, a different study in Anxi County, China, found that soil texture and organic matter content are the main factors (Deng *et al.,* 2016). The determinants could be different according to the locations. To the best of authors' knowledge, no such research has been conducted in the Upstream of Ciliwung Watershed.

Soil erosion rate can be determined by rainfall, runoff (Yustika *et al.,* 2019), topography (Tuo *et al.,* 2023), soil texture (Stanchi *et al.,* 2015), soil organic matter content (Obalum *et al.,* 2017), vegetation cover, land use (Lech-hab *et al.,* 2015), and human activities (Kemp *et al.,* 2020). Factors such as texture, structure, and organic content are parts of soil properties that influence the size and stability of soil aggregates, regulating the amount of soil lost to wind or water erosion (Tanner *et al.,* 2023). Other than soil properties, soil erosion is also significantly influenced by present vegetation coverage (Haigh, 2009; Wang *et al.,* 2022). Vegetation communities play important roles in an ecosystem, including increasing soil fertility, reducing erosion, and preserving biodiversity (Bishaw *et al.,* 2013), which can be evaluated through the diversity index and importance value (Budiastuti *et al.,* 2020). Therefore, soil properties and vegetation composition are significant factors that need to be considered in soil erosion studies.

The objective of this study is to examine the benefit of coffee agroforestry systems to control soil erosion by analyzing the influence of soil properties and vegetation composition on soil erosion rate in the system in the Upstream of Ciliwung Watershed.

2. Methodology

2.1 Study area

This study covers coffee agroforestry area in the upstream of Ciliwung Watershed located in Bogor Regency, West Java Province, Indonesia, with an area of about 15,000 hectares. This study focuses only on areas that practice coffee agroforestry system. The upstream is at the peak of Mount Gede Pangrango, Bogor, and its downstream is at Muara Angke, Jakarta. The upstream of Ciliwung Watershed is located approximately 600 – 1,500 meters above sea level. The annual rainfall in the Upper Ciliwung Watershed ranges from 2,862 – 4,458 mm/year and the annual average rainfall is 3,567 mm/year. The upstream of Ciliwung Watershed consists of seven subwatersheds, which are Cibalok, Cisukabirus, Ciseusepan, Cisuren, Ciesek, Cisarua, and Ciliwunghulu Subwatersheds (Figure 1). The research is conducted from July to September 2023.

2.2 Data collection and analysis

2.2.1 Coffee agroforestry locations

Information on the location of the coffee agroforestry practices in the study area is gathered through field survey. The research started from a location that is known to practice coffee agroforestry from an existing study (Fitri *et al.,* 2018), Ciliwunghulu Subwatershed. The research began in a hamlet, a residential area smaller than a village, called Cibulao. First, information was collected through interviews with a local expert from a Forest Farmer Group in Cibulao that practices coffee agroforestry. Forest Farmer Group is a group of farmers or individual Indonesian citizens and their families who manage forestry businesses inside and outside the forest area which includes timber forest products, non-timber forest products and environmental services, both upstream and downstream. The local expert then introduced other local experts who practiced coffee

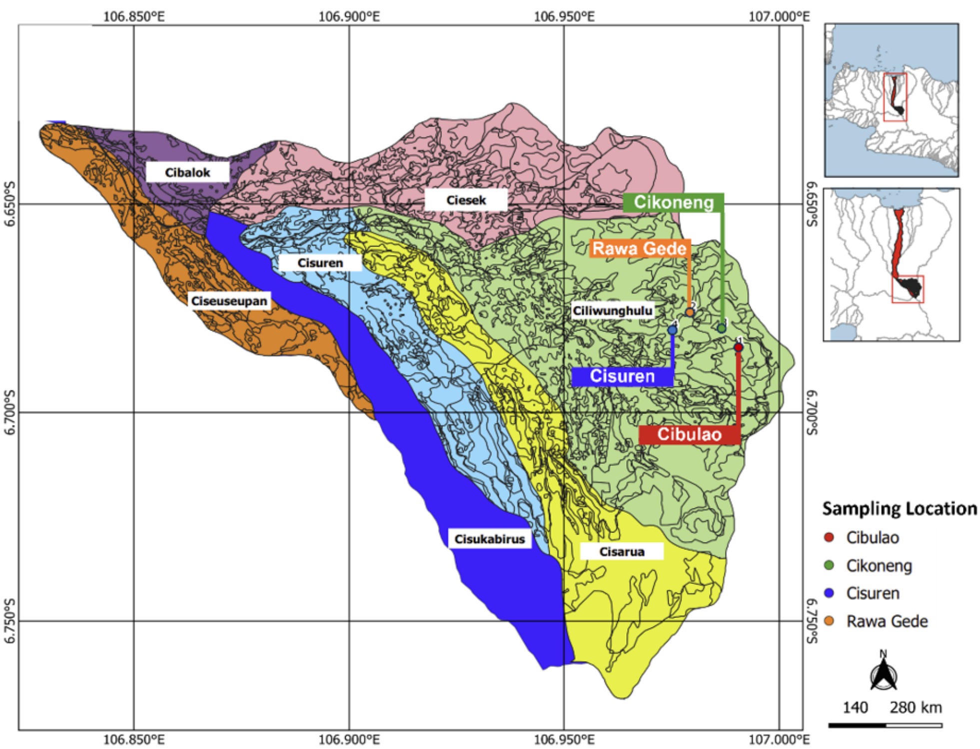

Figure 1. Study area (different colors showing different subwatersheds)
Source: BPDASHL (2023) with modification

agroforestry. Through this survey, information on four coffee agroforestry locations in the Ciliwunghulu Subwatershed were collected, namely Cibulao, Cikoneng, Rawa Gede, and Cisuren, was collected (Figure 1).

2.2.2 Soil properties

Soil samples from four research sites spread across four hamlets were taken to analyze their physical and chemical properties. These are analyzed because they influence the amount of soil lost to wind or water erosion (Tanner *et al.,* 2023). The soil sampling location is selected through purposive sampling where the soil does not look too dry or too wet and it is located in the middle of the field to avoid the edge effect. Soil sampling includes two types of samples, which are undisturbed soil samples, taken using ring samples, and disturbed soil sample, taken using a field hoe or soil drill. Each land unit soil samples were taken at a depth of 0 - 20 cm consisting of 3 ring samples of undisturbed soil, and 1 plastic sample of disturbed soil (composite soil sample) (> 500 grams). These soil samples are then brought to the Soil Laboratory of Department of Soil Science and Land Resources IPB University for analysis.

The undisturbed soil samples were used for physical properties analysis, including bulk density, analyzed using the Black and Hartge method; soil permeability; and soil structure obtained from field observations. Meanwhile, disturbed soil samples were used for chemical properties analysis, including nitrogen (N), phosphorus (P), potassium (K), soil texture analyzed by pipette method, and soil organic matter content by Walkley and Black methods. The soil chemical properties may be related to the vegetation composition, and the vegetation may have influences on the soil erosion.

2.2.3 Vegetation

Soil erosion is significantly influenced by present vegetation coverage (Wang *et al.,* 2022). Vegetation communities play important roles in an ecosystem, including increasing soil fertility, reducing erosion, and preserving biodiversity (Bishaw *et al.,* 2013), which can be evaluated through the Shannon diversity index and importance value (Budiastuti et al., 2020). Therefore, we considered vegetation coverage as a factor that determines soil erosion.

To analyze the vegetation coverage, we sampled the vegetation stand structure in 20-meter-wide belt-transect of 50-meter length in each sampling location. During vegetation survey, the width of the belt-transect must allow a convenient tree counting (Mueller-Dombois & H, 1975). Researchers are allowed to decide the plot dimension based on the convenience of measuring, as long as the plot size are the same for comparison (Baxter, 2014). The study areas are hilly, which makes the field survey quite challenging to complete. We divide the area into 10 subplots of 10 × 10 meters. In total, we surveyed 1000 square meters for each sampling location. The subplot size is decided after considering the range of the tree sizes is very large. Furthermore, a plot of 10 × 10 meters is considered appropriate for forest/ tree survey (Baxter, 2014).

The vegetation survey results are used to analyze the Shannon diversity index and the Importance Value. Shannon Index is probably the most commonly used index to measure species diversity (Spellerberg & Fedor, 2003). The Shannon diversity index is calculated as Equation (1).

$$H' = -\sum pi \times \ln(pi) \; ; \; pi = \frac{n_i}{N} \quad (1)$$

Where:
H’ = Shannon diversity index
ni = number of individuals of a species and
N = total number of individuals
pi = the proportion of individuals in species i.

Measurements that are used to assess the Importance Value (IV) of each species are counts, cover, density, and frequency. IV is calculated as IV = RA + RD + RF, where RA is relative abundance (the percentage of the number of individuals of species i), RD is relative dominance (the percentage of basal area of the plot occupied by species *i*), and RF is relative frequency (the proportion of plots where species *i* occurred). The IV calculation method by Curtis & McIntosh (1951) serves as an estimation to measure the ecological importance of shade species in the coffee agroforestry.

2.2.4 Soil erosion

Soil loss measurement is crucial to assess the extent of soil erosion in study areas. Measuring soil loss provides valuable data to estimate the effectiveness of coffee agroforestry practices for land rehabilitation, specifically in relation to erosion control. This study uses the Universal Soil Loss Equation (USLE) method to predict soil loss per year following Equation (1) by Wischmeier & Smith (1978). The USLE method is also used to predict tolerated erosion (Etol).

$$A = RKLSCP \qquad (2)$$

Where:
A = computed soil loss (tons/acre/year)
R = rainfall-runoff erosivity factor
K = soil erodibility factor
LS = slope length and steepness factor
C = cover management factor
P = supporting practices factor

Each component in the USLE method is described as follows.

1. R (Rainfall-runoff erosivity factor)

To determine the rainfall-runoff erosivity value (R), monthly rainfall data is acquired from the local meteorological station. The rainfall erosivity value is calculated using the Lenvain formula as follows.

$$R_{30} = 2.34\,(R_m)^{1.98} \qquad (3)$$

where R_{30} = monthly rainfall-runoff erosivity; R_m = monthly rainfall (cm).

The value of R for a year is obtained by summing R_m for a year.

2. K (Soil erodibility factor)

Data for calculating the soil erodibility factor (K) was obtained from (1) the percentage of fine sand, dust, clay, and organic matter from the analysis of soil samples in the laboratory; (2) soil structure and soil permeability, where both data are obtained through field observations and then the results are matched with a list of soil structure and soil permeability code values, (3) soil texture class (M), where the value is obtained using the formula: M = (s + d) (100 - c), where s is the percentage of fine sand; d is the percentage of dust, and c is the percentage of clay. The soil erodibility parameter was calculated based on the adjusted K value (Hammer 1981).

$$K = \frac{1.292[2.1\,M^{1.14}(10^{-4})(12 - a) + 3.25(b - 2) + 2.5(c - 3)]}{100} \qquad (4)$$

where:
K = soil erodibility
M = soil texture class (% fine sand + dust) (100 - % clay)
a = % organic matter
b = soil structure code
c = soil profile permeability code

3. LS (Slope length and steepness factor)

The slope length and steepness factor are determined based on data obtained from field measurements, using the equation in Arsyad (2006).

$$LS = \sqrt{X(0.0138 + 0.00965\,S + 0.00138\,S^2} \qquad (5)$$

where:
X = slope length (m)
S = slope steepness (%)

4. C (Cover management factor)

C values were determined based on interviews and field observations covering planting systems, fertilization, utilization of crop residues, soil treatment techniques, use of mulch, compost with reference to the C values of previous research results summarized in Hardjowigeno (2003).

5. P (Supporting practices factor)

The value of the P factor is determined based on soil conservation measures aimed at reducing soil erosion found in the field.

3. Results and Discussion

3.1 Soil condition

All four locations with coffee agroforestry in the study areas have inceptisol soil type. Slopes in Cibulao and Cikoneng range from 8% to 15%, meanwhile, slopes Rawa Gede and Cisuren are steeper, ranging from 16% to 25%. The analyzed properties of soil samples in study locations are presented in Table 1. The lowest nitrogen (N) value is found in Cibulao while the highest N value was in Cisuren. The highest phosphorus (P) level is found in Cibulao, while the lowest P value is in Cisuren. The lowest potassium (K) is found in Cisuren while the highest is found in Cibulao. The N, P, and K values are not entirely organic as coffee farmers in Cibulao are known to fertilize the plantation with P fertilizer to increase coffee productivity. The highest C-organic value is found in Cisuren at 17.33% and the lowest is found in Cibulao at 6.00%. All the pH values of the soil samples in the study area are acidic, with the most acidic pH is in Cisuren and the least acidic is in Cikoneng. According to soil textural triangle (USDA, 2018), the soils texture in Cibulao falls into the category “silty clay loam”. Meanwhile, soils in Cikoneng, Rawa Gede, and Cisuren fall into the category “silt loam”.

3.2 Vegetation composition

Based on the field survey, three of four observed coffee agroforestry areas Cikoneng, Rawa Gede, and Cisuren are composed of Arabica coffee (Coffea arabica). Only coffee agroforestry in Cibulao is composed of Robusta coffee (Coffea canephora). The ages of the coffee plantations vary in the study area. The age of the coffee in Cibulao and Cikoneng is more than 5 years, while in Cisuren is about 2 years. The youngest age of coffee is in Rawa Gede that is less than 1 year. Figure 2 illustrates the vegetation composition in the study area. According to a local expert, Arabica coffee is preferred due to its popularity and higher market price.

The vegetation composition and Shannon diversity index values in all four areas are presented in Table 2. The areas that have the highest to the lowest diversity index are Cibulao, Cikoneng, Rawa Gede, and Cisuren, respectively. Compared to other study areas, agroforestry in Cibulao has the highest species diversity despite having the lowest number of individuals.

Table 3 presents the importance values of vegetation in the study areas. In all four observed coffee agroforestry areas, coffee has the highest importance value compared to other species. This shows that coffee is the most dominant species in all observed areas. In Cibulao, *Coffea canephora* has the highest importance value and then followed by *Musa paradisiaca* (banana), which is also the second most abundant species in the study plots. The planting distance between coffee plants in Cibulao is approximately 3 × 2.5 m, which is the largest distance compared to coffee planting distance in other studied locations. This is due to the canopy diameter of mature Robusta coffee plants is generally larger than Arabica coffee. The large planting distance caused the total number of coffee individuals in Cibulao to become the smallest compared to the other three locations. Other than *Coffea canephora* and *Musa paradisiaca*, all species have relatively low importance value in Cibulao.

Table 1. Analyzed soil properties in the study areas

Hamlet Name	N (%)	P (ppm)	K (meq%)	Org-C (%)	pH	Texture		
						% Silt	% Clay	% Sand
Cibulao	0.51	187.8	2.29	6.00	4.53	42.27	28.76	24.33
Cikoneng	0.67	39.2	0.30	7.59	5.00	45.86	12.75	35.85
Rawa Gede	0.56	38.6	1.06	6.39	4.98	29.33	21.16	43.35
Cisuren	0.98	22.5	0.14	17.33	4.12	49.42	14.18	29.63

Note: N = Nitrogen, P = Phosphorus, K = Potassium, Org-C = Organic carbon
meq = milli equivalent

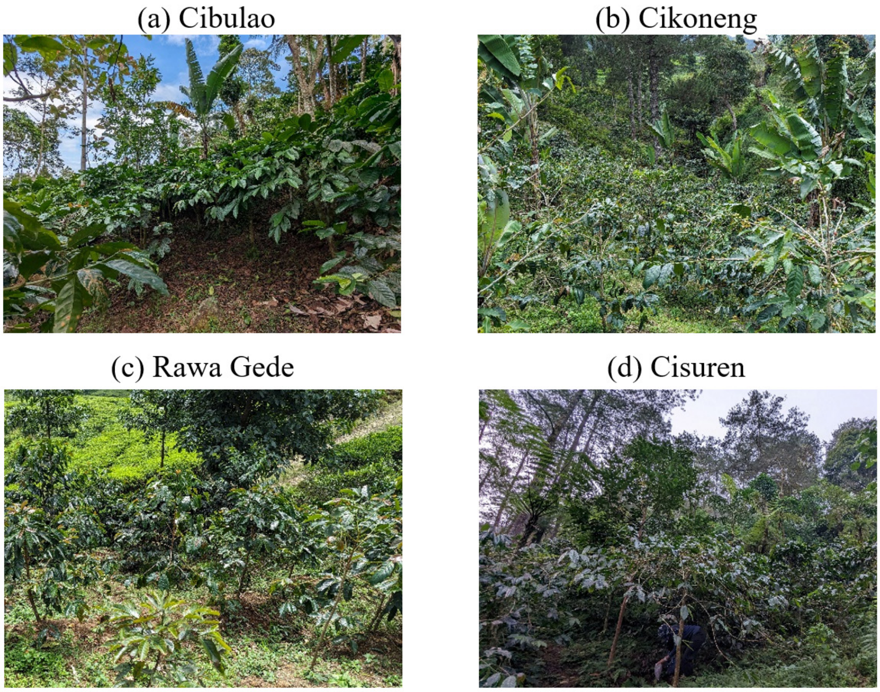

Figure 2. Vegetation composition in the study area

Table 2. Vegetation composition in the study areas

Hamlet Name	No of Species	Species	No of Individuals	H’
Cibulao	10	*Coffea canephora, Antidesma bunius, Artocarpus heterophyllus, Musa paradisiaca, Neolamarckia cadamba, Persea americana, Schima wallichii, Syzygium polyanthum, Toona sureni*	223 (Coffee: 196)	0.586
Cikoneng	9	*Coffea arabica, Agathis dammara, Cinnamomum* sp., *Citrus sinensis, Maesopsis eminii, Musa paradisiaca, Persea americana, Pinus merkusii, Toona sureni*	262 (Coffee: 236)	0.487
Rawa Gede	5	*Coffea arabica* var. *Gayo, Agathis dammara, Persea americana, Artocarpus heterophyllus, Cinchona* sp.	406 (Coffee: 389)	0.220
Cisuren	3	*Coffea arabica, Pinus merkusii, Cinchona* sp.	354 (Coffee: 337)	0.203

H’ = Shannon diversity index

Table 3. Importance values of vegetation species in the study areas ("-" means the species is not found in the sampling location)

Species	Importance Value / Sampling location			
	Cibulao	Cikoneng	Rawa Gede	Cisuren
Coffea canephora	169.030	-	-	-
Coffea arabica	-	156.932	213.329	149.866
Agathis dammara	-	16.466	43.103	-
Antidesma bunius	6.940	-	-	-
Artocarpus heterophyllus	4.950	-	5.155	-
Cinchona sp.	-	-	18.916	5.351
Cinnamomum sp.	-	3.720	-	-
Citrus sinensis	-	3.644	-	-
Maesopsis eminii	-	14.301	-	-
Musa paradisiaca	45.663	45.505	-	-
Neolamarckia cadamba	23.673	-	-	-
Paraserianthes falcataria	10.749	-	-	-
Persea americana	13.973	3.665	19.497	-
Pinus merkusii	-	51.919	-	144.782
Schima wallichii	9.567	-	-	-
Syzygium polyanthum	5.556	-	-	-
Toona sureni	9.900	3.848	-	-

Cikoneng has the second highest Shannon diversity index (0.487) with nine species found in the study plots (Table 2). The planting distance between coffee plants in Cikoneng is approximately 2×2 m. After *Coffea arabica*, *Pinus merkusii* (pine) has the second largest importance value (Table 3). *Pinus merkusii* has the highest dominance, even surpassing *Coffea arabica* that has the highest abundance and frequency, due to the large size of the *Pinus merkusii* trees. The second largest abundance and frequency in the study plots belongs to *Musa paradisiaca*, which seemingly is a common coffee shade tree in Cibulao and Cikoneng.

Rawa Gede has the highest number of individuals including five different species (Table 2). The coffee plants species in Rawa Gede is *Coffea arabica* var. *Gayo*, different than the other study locations. The mature size of this variety is smaller than regular Arabica coffee, which allows a smaller planting distance of around 1 to 1.5 m between each plant thus resulting in higher coffee abundance. In Rawa Gede, the second highest importance value belongs to the species *Agathis dammara* (dammar pine), which seemingly a native plant that has been around for years.

Cisuren has the lowest Shannon diversity index among the study areas (Table 2). Other than *Coffea arabica*, there are two species in coffee agroforestry Cisuren, which are Pinus merkusii and *Cinchona* sp. (Table 3). The importance values of *Coffea arabica* and *Pinus merkusii* are not much different despite having a significant difference in the species abundance. The size of *Pinus merkusii* trees in the study area are very large and the dominance takes 92.64% of the study plots. The planting distance between coffee plants in Cisuren is approximately 1.5×1.5 m. The local figure in Cisuren acknowledges that this planting distance is too close, which results in crowded coffee plants and makes field maintenance hard because unwanted weeds grow quickly. Moreover, the plantation is on a hilly slope, so the environment is rather dark and damp due to the shades from *Pinus merkusii*, an endemic species the study plots.

3.3 Soil erosion

Based on the analysis, the erosion rates in the study areas are below tolerated erosion rates (Table 4). The highest erosion rate is found in Cikoneng (14.76 tons/ha/year with an erosion tolerance of 16.38 tons/ha/year) and

Table 4. Soil erosion in the study areas

Hamlet Name	R	K	LS	C	P	Erosion (A) (ton/ha/year)	Tolerated Erosion (Etol) (ton/ha/year)	Difference (Etol−A)
Cibulao	2733,10	0,06	1,20	0,10	0,50	9,84	18,33	8.49
Cikoneng	2733,10	0,09	1,20	0,10	0,50	14,76	16,38	1.62
Rawa Gede	2733,10	0,05	4,25	0,20	0,10	11,62	15,76	4.14
Cisuren	2733,10	0,04	4,25	0,20	0,10	9,29	16,77	7.48

the lowest is found in Cisuren (9.29 tons/ha/year with an erosion tolerance of 16.77 tons/ha/year). The difference between predicted erosion (A) and tolerated erosion (Etol) rates from the highest to the lowest is in Cibulao, Cisuren, Rawa Gede, and Cikoneng.

3.4 Influence of soil condition and vegetation composition on soil erosion

Land slope is a significant factor in soil erosion. Existing research show that steeper slopes generally experience higher erosion rates because water (rainfall or runoff) can move faster and with greater force, carrying away soil particles (Sarminah *et al.,* 2022; Siswanto & Sule, 2019; Taye *et al.,* 2013). A study conducted in the mountainous region of Central Java, Indonesia, observed a positive correlation between slope steepness and erosion rate. That study revealed a 7 – 15% increase in erosion rate for every 1% rise in slope steepness (Rahardjo *et al.,* 2021). Rawa Gede and Cisuren have steeper slopes than Cibulao and Cikoneng. However, the erosion rates in Rawa Gede and Cisuren are not necessarily higher than Cibulao and Cikoneng. The highest erosion rate is found in Cikoneng (erosion rate of 14.76 ton/ha/year; slope steepness of 8 – 15%) and the lowest is found in Cisuren (erosion rate of 9.29 ton/ha/year; slope steepness of 16 – 25%). Unlike generally predicted cases where steeper slopes should increase the soil loss, a study argues that steeper slopes can have equal or less common landslides due to differences in soil thickness (Prancevic *et al.,* 2020). According to the said study, the stability of soils is maintained through cohesive forces from plant roots and mineral cohesion, and steeper slopes are associated with thinner soil, hence thinner soils are more securely anchored. After reaching their peak erosion at approximately 30^{o} hillslopes, the erosion rapidly decreases for steeper slopes. This may explain a similar phenomenon found in the study areas considering the soil sampling spot in Cisuren is indeed on a steeper hill compared to the spots in the other three locations.

It is also noteworthy that Cisuren has the highest organic matter content and the lowest Shannon diversity index. This finding contradicts an existing study that found that soil organic matter content is positively correlated with vegetation diversity (Yan *et al.,* 2023). However, another study argues that the vegetation diversity is not determined by the quantity of organic matter, but rather by the quality of organic matter (Spohn *et al.,* 2023). The assessment of organic matter quality in the study area remains uncertain as it has not undergone analysis, though this remains a potential consideration for future studies. A multi-temporal study in Hainan Island, China, states that after 7 years difference, the soil organic matter increases while the plant species diversity decreases (Yaseen *et al.,* 2022). In the present study, coffee plant (*Coffea* sp.) has the highest importance value in all study areas, and the differences between them and the species with the second highest importance value are significant. An exception is found in Cisuren where the importance value of pine trees (*Pinus merkusii*) is almost as high as the value of coffee plants with 149.866 for pine trees and 144.782 for coffee plants. Pine trees are recognized for their efficacy in erosion control because of their high interception and thick litter (Rosmaeni *et al.,* 2022). The mentioned study found that an increase in pine trees canopy coverage would decrease the soil erosion rate, even on slope with more than 40% steepness. However, pine litter is known to have allelopathy that inhibit the understory growth of the forest (Retnoningrum & Setiawan, 2021), which may explain the low Shannon diversity index in Cisuren. Furthermore, Cisuren seems to be the most undisturbed coffee agroforestry land compared to other locations. We suggest that land with low disturbance has higher organic matter and can provide greater benefits in soil erosion control.

Soil organic matter content may have a more significant impact on soil erosion compared to vegetation diversity considering organic matter acts as a binding agent in soil, helping to create stable soil aggregates. These aggregates enhance soil structure, reducing soil erosion and improving water infiltration and retention (Bronick & Lal, 2005). The ideal soil physical properties to decrease erosion include a dense layer of vegetation cover, a consistent soil structure with stable aggregates, a high level of soil organic matter, and a well-drained soil with good permeability (Zhu *et al.,* 2022). In degraded lands where soil structure may have deteriorated due to erosion or compaction, increasing organic matter content can help rebuild soil structure.

The Shannon diversity index values in all study areas are less than one (Table 2). Usually, a diversity index value ranges from 1.5 to 3.5 (Ortiz-Burgos, 2016) in a regular forest condition. Considering the study areas are coffee agroforestry areas, the low values are likely due to low species evenness as all sampling locations are dominated by coffee. The diversity of vegetation plays a significant role in maintaining soil quality and health (Shen *et al.,* 2022). A mix of species creates a diverse root structure, improving soil structure and water retention, reducing erosion, and increasing nutrient cycling (Liu *et al.,* 2015). Different plant species also deposit varying amounts of organic matter, increasing soil fertility and microbial diversity (Furey & Tilman, 2021). The lowest organic matter content is found in Cibulao, which is also the only coffee agroforestry that incorporates *Coffea robusta*, while the others incorporate *Coffea arabica*. Cibulao also has the highest Shannon diversity index of 0.586, with the second most important species is *Musa paradisiaca* or banana tree. Banana trees have less litter compared to pine trees, which may explain the reason behind the low organic matter content despite having the highest Shannon diversity index.

4. Conclusion

This study examined four hamlets that practice coffee agroforestry in the upstream of Ciliwung Watershed to analyze the effectiveness of coffee agroforestry for soil erosion control. The findings of this study suggest that the implemented coffee agroforestry systems in the study areas manage to keep the soil erosion rates below the tolerated thresholds, indicating a positive impact on soil conservation in the study areas.

The study emphasizes that there are complicated dynamics of soil erosion within the coffee agroforestry system. It is evident that the soil erosion rate is not solely dependent on individual factors, such as soil properties or vegetation cover, but rather on the combination of these elements. The area that has the lowest soil erosion rate is Cisuren, a sample with high slope steepness, highest organic matter content, and lowest Shannon diversity index. Suggestion was that the primary determinant of soil erosion rate is not vegetation diversity; rather, it could be the specific species of vegetation and their characteristics that may significantly influence soil organic matter content, playing a more substantial role in the erosion process.

Overall, these findings contribute valuable insights to the sustainable land management practices in the studied watershed, offering a foundation for further research and the development of targeted strategies aimed at enhancing the resilience of agricultural landscapes against soil erosion in similar geographical contexts.

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