Plot scale comparison of runoff generalization between forest and coffee combination cassava landcover in Kuta Jungak Village, Siempat Rube District, Pakpak Bharat Regency

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Abstract. It has become a public opinion that forests will always reduce the amount of surface runoff compared to other types of land cover. However, previous research reports that the runoff generalization process is still not fully explained. The activity of converting forests into agricultural land will also have an impact on surface runoff. This study aims to compare the magnitude of surface runoff on the plot scale between forest and coffee combination cassava fields. The surface runoff measurement plot with a size of 8 x 10 meters in the direction of the slope. The higher average surface runoff occurs in a forest plot that is equal to 0.286 ± 0.438 mm, while coffee and cassava plots produce an average surface flow of 0.022 ± 0.057 mm. Understorey and litter are influential in generalizing runoff in both plots. The understorey vegetation cover in the forest plot is lower than in the coffee combination cassava plot. This research confirms the results of previous studies that forests with less understorey vegetation conditions and less litter cover the soil surface can still produce high runoff results.

1. Introduction

Forest conversion impacts on hydrological function mainly through the transformation of rainfall into surface runoff [1]. Most of the changes in forest cover in Indonesia are conversion to plantations and agricultural land [2, 3]. Although economically profitable, uncontrolled forest conversion will have a negative impact on ecological functions [4]. Forest function can be observed from the hydrological response of the watershed to the amount of rainfall input in the region. Forests have essential hydrological functions, mainly in distributing the amount of rainfall that falls and reduce the runoff [5].

Forest area, other vegetation areas, slope, soil type, rainfall characteristics, soil moisture, and weather conditions during rain affect the watershed hydrological response [6]. Vegetation has a vital role in inhibiting the kinetic energy of the rainfall so as not to damage the soil structure. Land with no vegetation cover has a low ability to infiltrate water into soils. Saturated soils are unable to infiltrate rainwater so that runoff occurs. Surface runoff is part of rainfall that cannot be absorbed by the soil because the soil is still in a saturated state. Surface flow has kinetic energy, which can cause erosion in the soil. The results of erosion on the surface of the soil will be carried by water into sedimentation. The conversion of forest land into agriculture has an impact on changing hydrological functions.
Pakpak Bharat Regency is one of the regencies in North Sumatra province with an area of 1,218.3 km², where 81% of the area is forested. The Pakpak Bharat community generally develops high-value forest plants such as Patchouli (*Pogostemon cablin* Benth), Gambir (*Uncaria gambir* Roxb), and Rubber (*Hevea brasiliensis*). The Pakpak Bharat community has a livelihood as a farmer, and the forest area has begun to decrease due to the conversion of forest land into agriculture and agroforestry. Kuta Jungak Village is one of the villages of the Siempat Rube sub-district, which has a majority of farming communities. Land conversion carried out excessively by farmers will have a negative impact on the ecology of the surrounding area, generally on the hydrological function. This study aims to analyze the response of surface runoff that occurs on forest land and agricultural land and analyze the factors that influence surface runoff at the scale.

2. Materials and Method
This research was carried out in Kuta Jungak Village, Siempat Rube I, Siempat Rube District, Pakpak Bharat Regency (figure 1). The research was conducted from November 2018 until February 2019.

![Map of research site](image1.png)

**Figure 1.** Map of research site

2.1. Tools and materials
The tools used are rain gauge, water meter, a surface flow collection box for runoff measurement. The soil sample ring, clinometer Suunto, and densiometer for plot characteristic measurement. GPS, drone, and ArcGIS 10.3 software for land cover mapping.
2.2. Field preparation
The study began by conducting a survey in the field to take analyzed soil samples, measure altitude, coordinate measurements, and description of land use. After the survey, a measuring plot with an area of 86 m$^2$. The design plot of the surface flow measurement constructed is as presented in Figure 2.

![Figure 2. Plot design of surface flow measurements](image)

Surface flow volume measurements are carried out for each rainy event by measuring the volume of water in the storage box and recording the numbers on the water meter. Soil sampling was done by purposive sampling with two replications in each plot. Soil sampling is not interrupted by using a soil sample ring at a depth of 5-15 cm and a depth of 15-30 cm from the soil surface so that four soil sample rings are obtained. Soil sampling was disrupted by the composite method in each of the measurement plots. Soil samples were taken (outside of the plot) at two sampling points at two soil depths to obtain four plastic soil samples. Soil samples are taken to analyze bulk density, organic matter content, and soil texture.

2.3. Data analysis
Data analysis was performed by calculating the amount of surface water from each plot for each rainfall event. The next step is to calculate the average rainfall and runoff average for each plot.

3. Results and Discussion

3.1. Plot characteristics
Plot conditions have relatively uniform slope characteristics, between 25% to 26%. Forest land has a percentage of site cover by understorey ± 40.21%. The forest plot has a canopy density of ± 70% and there is a large canopy gap at the end of the plot triangle. The plots of cassava combination coffee fields have a lower percentage of plants ± 96.88%. The condition of the land cover of the research plot is presented in Figure 3.

Human activities that occur in forest plots are the harvesting of rubber sap and the extract of cinnamon bark. There is a path that is commonly used by the community to harvest sap and cinnamon water in a forest plot. Human activities that occur in the coffee and cassava plots are soil processing and also cassava and coffee harvesting. Field plots have dark topsoil and evenly spread under vegetation in plots. Details of the conditions of the two study plots are presented in Figure 4.
Figure 3. Condition of land cover in both study plots

Figure 4. Detailed plot conditions (a) forest and (b) coffee combination cassava

3.2. Soil physical and chemical properties
Organic matter content, dust fraction, clay fraction, the sand fraction of each plot at a depth of 0-15 cm, and a depth of 15-30 cm are presented in table 1. A soil depth of 0-15 cm in the forest plot has sandy clay texture. The clay fraction is the most difficult fraction in passing water because clay has the smallest particle size compared to dust and sand. Clay will undoubtedly reduce the ability of forests to infiltrate and turn rainwater into surface runoff. Soil texture of cassava combination plot of coffee fields on soil layer 0-15 cm is sandy. This texture can infiltrate water into the soil higher than the texture of sandy loam. Soil texture that supports and the presence of understorey that evenly covers the cassava plot will undoubtedly minimize the occurrence of surface runoff events.
Table 1. Results of analysis of physical and chemical properties of soil in each plot

| Plot            | Soil depth (cm) | Organic matter (%) | % dust | % clay | % sand | Soil texture    | Bulk density (g/cm³) |
|-----------------|-----------------|--------------------|--------|--------|--------|----------------|---------------------|
| Forest          | 0 - 15          | 12.57              | 31.73  | 3.98   | 64.29  | Sandy loam      | 0.61                |
|                 | 15 - 30         | 7.82               | 7.49   | 1.18   | 92.49  | Sand           | 0.67                |
| Cofee combination cassava | 0 - 15         | 8.13               | 7.52   | 1.18   | 92.46  | Sand           | 0.65                |
|                 | 15 - 30         | 4.33               | 14.40  | 3.61   | 81.98  | Loamy sand     | 0.70                |

The level of soil organic matter (SOM) in the forest plot is 0-15 cm at 12.57% and at a depth of 15-30 cm at 7.82%. Sedimentation in coffee and cassava plots is 8.13% at depth 0-15 cm and at a depth of 15-30 cm is 4.33%. Forests have higher soil organic matter. SOM has a role in helping to absorb water into the soil. The soil bulk density of the two plots is not significantly different. However, forest plots have a lower bulk density. Human activity in the plot results in specific patches having solidified soil (figure 4). We found a path that the community used on the forest plot. Soil compaction that occurs will undoubtedly reduce the ability of the soil to absorb water so that it can trigger a surface runoff. Soil absorption will decrease if there is continuous rain, compared to rain, that has a period. If the new soil absorbs rainwater and does not lapse in a long time, it rains, surely the land will reach saturation concentration faster so that surface runoff occurs [7].

3.3. Rainfall characteristics

The results of rainfall measurements at the study site for four months starting from November 2018 to February 2019 obtained a total rainfall of 680.76 mm with 32 days of rain. The lowest daily rainfall recorded was 1.78 mm, and the highest was 124.84 mm, with an average daily rainfall of around 21.27 mm. The highest average rainfall is in January 2019 of 41.88 mm with five rainy days, and the lowest occurred in December 2018, amounting to 11.40 mm. Most rainy days arise in February 2019, which is 13 days. The distribution of daily rainfall during the study was concentrated below 20 mm per day, which reached 24 rainy days, with a total of 214.39 mm. The highest total daily rainfall is on the daily rainfall above 30 mm, which achieves 880.1 mm with a rainy day of 16 rain days (Figure 5).

3.4. Runoff

The average surface runoff occurs in a forest plot that is equal to 0.286 ± 0.438 mm, while coffee and cassava plots produce an average surface flow of 0.022 ± 0.057 mm. However, forest plots provide a higher variation in runoff quantities. Runoff coefficient varies significantly from one rainstorm to another, which is the reason that at the beginning of the storm, rainfall is absorbed in the soil and fills the soil macropore after the infiltration process is complete, then a runoff is formed [8]. Forests have lower vegetation cover than coffee and cassava plots. This result shows that the presence of undergrowth and litter can reduce the surface flow that occurs when it rains (figure 6). Litter can function to reduce the portion of rainfall that reaches the surface into surface runoff [9].

Litter also increases the ability of the soil to absorb water. Litter loss increases surface flow and erosion. Forest plots have less litter and understory. The presence of litter in the form of leaves, stems, and fruit is only found at the bottom of the tree and is not spread evenly. Coffee and cassava plots have a lower canopy cover but have a ground cover in the form of evenly distributed understory. Areas that are not covered with litter will find it difficult to infiltrate water into the soil. The litter loss could increase surface flow from 0.6% to 4.1% [10]. The undergrowth factor in each plot plays an essential role in the surface runoff that occurs. Appropriate land maintenance can also help minimize the occurrence of surface runoff [11]. This condition will undoubtedly have an impact on groundwater replenishment due to the high surface runoff and low infiltration.
Figure 5. Distribution of rain classes and rainy days from each rain class

![Graph](image1)

**Figure 6.** Average surface runoff in each plot

Roots can help infiltrate water into the soil and reduce surface runoff [12]. Land management activities that result in soil compaction can change infiltration capacity and eliminate surface hydrological functions to increase infiltration [13] suggested that activities that cause soil compaction are reported to have significantly increased the soil weight (BI) content and decreased the total porosity and macroporosity of the soil. This study also confirms the results of previous studies that tillage influences the runoff process [14].

Water storage capacity and leaf shape of the litter layer affect the generation of surface runoff. The decrease in rainfall threshold for the production of surface runoff and the increase in surface runoff produced may be related to the development of hydrophobic conditions at the ground surface caused by dry conditions. Groundwater conditions can also be an essential factor in the evaluation of the plot scale of the generation of surface runoff from slopes covered with litter layers [15]. Furthermore, a land system in the form of forest cover will still have the potential to have a significant surface runoff if it does not have a useful tread layer [5].

Although this research shows, the forest plot produces a higher average runoff, this is likely due to the influence of the plot scale. Runoff depth or runoff coefficient will tend to decrease with increasing size [8]. The primary mechanism of this scale effect is run-on infiltration, but rainfall intensity and soil
properties can influence scaling trends through their interaction with run-on. The scale effect can be reduced at higher rainfall intensity and lower temporal variability [16].

The coefficient of determination of the relationship between rainfall and runoff shows that variations in rainfall can explain 69.1% of the surface runoff that occurs in forest plots. While in the coffee field plot and the combination of rainfall, coffee can explain 70.2% of the surface runoff that arises. Other factors such as slope, understorey density, soil texture, soil bulk density, soil organic matter need further study. In addition to natural elements, human factors can also affect surface runoff, such as tillage, soil compaction, and vegetation removal activities.

Previous research confirms that variations in scale factors are not well explained by area differences alone [15, 16]. The runoff generation scale effect is better explained by extrapolating runoff coefficients based on representations of different watershed characteristics. Thus, extrapolation practices in runoff modeling and scaling efforts of soil and water conservation practices must carefully consider the effects of scale [17].

4. Conclusions
Forest plots provide higher runoff yields than coffee and cassava plots. However, caution is needed in generalizing land cover on a broader scale. The condition of understorey cover and litter in both plots is a factor influencing runoff generalization. The existence of human activities in the plot during the study also changed this runoff produce.

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