Analysis of soil physical properties and infiltration rates for various landuses at Gunung Dahu Research Forest, Bogor District, West Java Province

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Abstract. Assessment of the ability of the soil to absorb water can be known from the value of the infiltration rate. This study was conducted to examine the physical properties of soils and infiltration rates, analyze the relationship between physical properties of soils and their infiltration rates and determine the best infiltration models for various land uses. The data is processed using the Horton and Kostiakov infiltration model. Correlation analysis and R tests were performed to compare the field infiltration rate with the model prediction results. The results showed that the physical properties and infiltration capacity in the three land uses differed significantly on several parameters of physical properties such as drainage pore, permeability and infiltration with sequential values in the stands of S. leprosula, S. selanica and tourism objects were 3.21%, 2.29%, 3.51% for the parameters of fast drainage pores and 7.84%, 8.67%, 7.49% for slow drainage pore. Whereas the average permeability values are 1.37 cm / hour, 2.13 cm / hour, 3.39 cm / hour. Based on the results of field infiltration measurements, it was found that the S. selanica stands had the highest infiltration rate with a value of 15.5 cm / hour. The results of the correlation test and regression test between the field infiltration rate and the Horton infiltration model rate were not significantly different so that the Horton infiltration model can be used for the infiltration rate of soils in the Gunung Dahu Research Forest.

1. Introduction
Soil and water have undeniably significant correlations. One of their forms of interrelationship is shown through the process of groundwater formation [1]. The amount of water resources has not changed but the amount of water that can be used has become increasingly limited. This is seen in terms of quantity, quality and time of availability. Conversion of forest land can cause a decrease in soil function associated with low water infiltration into the soil, reduce soil physical properties, and increase surface runoff [2].

Soil physical properties greatly affect groundwater movement, percolation and availability of water in the ground [1]. Different land use and vegetation types prompt dissimilarities in soil physical properties in terms of textures, structures, permeability and infiltration. Different physical properties of the soil will affect its ability to absorb water [3]. The ability of the soil to absorb water is known as infiltration. Infiltration is the process of flowing water into the ground [4]. [3] underlined that infiltration is a principal component in the field of soil and water conservation.
Characteristics of infiltration rate are influenced by several factors such as soil texture and structure, soil moisture, biological activities and organic elements, type and thickness of litters, as well as types of vegetation and undergrowth. Different land use shows variations in vegetation cover. Each type of vegetation has a different root system and produces different amounts of soil organic matter. This will affect the rate of infiltration into the soil due to improvements in soil physical properties such as the formation of soil structure and increased soil porosity [5].

Nowadays, land use oftentimes does not pay attention to the aspect of soil and water conservation. Land conversion tends to cause low absorption of water into the soil. This results in a reduction in the amount of water reserves and high surface runoff due to reduced ability of the soil to absorb and retain water. In Gunung Dahu research forest, certain areas have been converted into tourist attractions such as Panorama Pabangbon 2, Bukit Pabangbon and Curug Cilame entrance. This will certainly affect the absorption of water into the soil. Therefore, it is necessary to study the physical properties of the soil and the rate of field infiltration in various land uses in Gunung Dahu Research Forest. However, measurement of field infiltration rates requires considerable time, energy and cost [6] hence infiltration approximation models are developed. The use of the right model will affect the expected results of infiltration rate. Thus, finding correlations between the rate of field infiltration and the Horton and Kostiakov infiltration models are indispensable in order to obtain the best infiltration estimation model that can be used in Gunung Dahu Research Forest.

This study aims to determine physical properties of the soil and the rate of field infiltration, to analyse the relationship between soil physical properties and infiltration rate, as well as to compare the value of field infiltration with the Horton’s and Kostiakov’s infiltration models on various land uses in Gunung Dahu Research Forest. Similar studies have been conducted numerously, but this research proposed a deepened observation of soil morphology and its texture, where soil texture itself is correlated to many other environmental changes.

2. Materials and Method

2.1. Study location

Research were conducted along December 2019 to March 2020 at Plot number 1, 2 and 6 (S. Leprosula stands), plot number 10 and 11 (S. Selanica stands) of Gunung Dahu Research Forest, as well as tourist attractions of Panorama Pabangbon 2, Bukit Pabangbon and Curug Cilame entrance, Bogor, West Java. Soil samples were analysed in the Services Laboratory of Plant and Soil Analysis, SEAMEO BIOTROP Bogor.

Figure 1. Location map for data collection
2.2. Implementation stage

2.2.1. Plot establishment
Plotting was set up under the stands of *S. leprosula* Miq., the 22-year-old *S. selanica* Miq., and in the tourism objects including Panorama Pabangbon 2, Bukit Pabangbon and Curug Cilame entrance. For each land use, three circular plots measuring 17.8 m in size were established. Placement of plots was done by purposive sampling, with an aim to obtain plots that represent each observed land use by considering stand’s condition and distinct land uses.

2.2.2. Infiltration rate measurement
Infiltration rate in the field was measured using a double ring infiltrometer. Ring installation was done carefully to reduce soil damage, especially soil aggregates. The rings were inserted into the soil by pressing, then water was filled into the inner and the outer rings. The decline of water surface in the ring was measured using ruler. Observations were carried out until a constant decrease with an interval of one minute. Infiltration rate measurements were performed with three replications on each plot of 0.1 ha (with 17.8 m radius). The rate is calculated using the following equation:

\[ f_t = \frac{\Delta h}{\Delta t} \]  

Where:
- \( f_t \): infiltration rate (mm/minute),
- \( \Delta h \): declining water level (mm),
- \( \Delta t \): time (minute)

2.2.3. Crown density measurement
Crown density was measured using a densiometer. Measurements were carried out in each observation plot with 3 replications for each land use. The density is determined by the square unit shown on the densiometer. Measurement results range from 1-100 and denoted in a percentage (%).

2.2.4. Forest undergrowth diversity
Observations on undergrowth diversity took places around the infiltration rate measurement site. They were performed by making a plot measuring 1 x 1 m, with 3 replications. Acquired data were then identified and the index of importance value, abundance, evenness and dominance were also calculated.

2.2.5. Litter depth measurement
Litter thickness was measured on each observation plot with an aim to obtain supporting data that might affect the rate of infiltration. The method of measurement was done using a ruler for five times at each observation point.

2.2.6. Soil morphology observation
Observations of soil morphology were done through drilling and soil sampling at each observation plot of *S. leprosula* and *S. selanica* stands, as well as in the tourism objects involving Panorama Pabangbon 2, Pabangbon Hill, and Cilame Curug entrance. In this study, drilling was performed with a 100 cm depth by observing aspects of texture, colour, adhesiveness and plasticity.

2.2.7. Intact soil sampling collection
Intact soil sampling procedures were carried out to as many as 27 samples divided into 3 land uses. Each land use has 3 circular observation plots with a radius of 17.8 m. Intact soil samples were taken with 3 replications. It was performed using ring sample, with a main purpose to analyse total pore space, soil texture, drainage pore, permeability and bulk density.
2.3. Data analysis

Data findings obtained in the field were processed descriptively, then they were analysed using analysis of variance to determine the effect of land use on soil physical properties and infiltration capacity and further examinations were conducted using Duncan’s test at 5% level. In addition, correlations between soil physical properties and infiltration rate were calculated using a paired sample t-test. Following that, data calculation using Horton and Kostiakov infiltration models were performed with the following formula:

\[ f_t = f_c + (f_o - f_c) e^{-kt} \] (2)

Where:
- \( f_t \) = infiltration rate (mm/hour),
- \( f_c \) = constant rate of infiltration (mm/hour),
- \( f_o \) = initial infiltration (mm/hour),
- \( e \) = natural number (2.718),
- \( k \) = a constant,
- \( t \) = time (hour)

\[ f_t = K t^n \] (3)

Where:
- \( f_t \) = infiltration rate (mm/hour)
- \( K,n \): the constant influenced by land and initial water content factors
- \( t \) = time (hour)

Afterwards, data were tested for regression and Pearson’s correlation coefficient to determine the degree of correlation between the value of field infiltration rate and Horton’s calculation model using regression analysis and correlation test.

3. Results

3.1. Crown density

Crown is a part of the tree which is an extension of twigs and branches. The crowns have a huge role in determining the rate of infiltration. Crown density in an area will affect the amount of water that hits the ground surface directly. Based on observations, the highest crown density value was found on S.leprosula stands with an average of 82.11%. Meanwhile, the lowest was found on trees in tourism objects (Table 1).

| Land-use          | Crown density level (%) | Average (%) | Crown density class |
|-------------------|-------------------------|-------------|---------------------|
| S. leprosula stands | 73.00                   | 76.94ab     | High                |
|                   | 79.50                   |             |                     |
|                   | 74.33                   |             |                     |
| S. selanica stands | 87.83                   | 82.11a      | High                |
|                   | 84.16                   |             |                     |
|                   | 45.50                   |             |                     |
| Tourism site      | 54.50                   | 56.11b      | Medium              |
|                   | 68.30                   |             |                     |

Remarks: Values with different indicate significantly different at (p <0.05).
3.2. The state of soil physical properties in various land uses

3.2.1. Description of soil morphology
Based on the study, each land use has a relatively similar colour of dark reddish brown and reddish brown. This reddish colour is generated by iron oxide. Soil that has never been submerged in the water tends to be red or reddish due to the presence of iron, in this case an oxidised Fe, enabling it to turn red or reddish colour [7]. It can be seen in Table 2 that the upper layer has a darker color compared to the lower layer.

| Land use  | Plot | Depth (cm) | Colour name            | Notation   | Texture | Consistency       | Stickiness | Plasticity  |
|-----------|------|------------|------------------------|------------|---------|--------------------|------------|-------------|
|           |      |            | Dark reddish gray      | 2,5 yr 3/1 | Clay    | sticky             |            | Rather plastic |
|           | 1    | 0-7cm      | Dark reddish brown     | 2,5 yr 3/2 | Clay    | sticky             |            |             |
|           |      | 8-20cm     | Dark reddish brown     | 2,5 yr 3/3 | Clay    | Very sticky        | Plastic    |             |
|           |      | 21-40cm    | Dark reddish brown     | 2,5 yr 4/4 | Clay    | Very sticky        | Plastic    |             |
|           | 2    | 41-100cm   | Reddish brown          | 2,5 yr 3/3 | Clay    | Very sticky        | Plastic    |             |
| S. leprosula stands | | 0-10cm     | Dark reddish brown     | 2,5 yr 3/3 | Clay    | Very sticky        | Plastic    |             |
|           |      | 11-34cm    | Dark reddish brown     | 2,5 yr 3/4 | Clay    | Very sticky        | Plastic    |             |
|           | 3    | 61-100cm   | Reddish brown          | 2,5 yr 4/4 | Clay    | Very sticky        | Plastic    |             |
|           |      | 0-20cm     | Dark reddish brown     | 2,5 yr 3/3 | Clay    | sticky             | plastic    |             |
|           |      | 21-27cm    | Dark reddish brown     | 2,5 yr 3/3 | Clay    | Very sticky        | plastic    |             |
|           |      | 28-40cm    | Dark reddish brown     | 2,5 yr 3/6 | Clay    | Very sticky        | Plastic    |             |
|           |      | 41-100cm   | Dark red               | 2,5 yr 3/6 | Clay    | Very sticky        | Plastic    |             |
| S. selanica stands | | 1    | 0-7cm      | Dark reddish brown     | 2,5 yr 2.5/3 | Clay | Very sticky | Very plastic |
|           |      | 8-20cm     | Dark reddish brown     | 2,5 yr 2.5/4 | Clay | Very sticky | Plastic |
|           |      | 21-100cm   | Dark red               | 2,5 yr 3/6 | Clay | Very sticky | Plastic |
|           | 2    | 0-11cm     | Dusky red              | 2,5 yr 3/2 | Clay | Sticky        | plastic    |             |
|           |      | 12-20cm    | Dark reddish brown     | 2,5 yr 3/3 | Clay | Very sticky | plastic    |             |
|           | 3    | 21-100cm   | Red                    | 2,5 YR 4/6 | Clay | Very sticky | Plastic    |             |
|           |      | 0-10cm     | Dusky red              | 2,5 yr 3/2 | Clay | Very sticky | Plastic    |             |
|           |      | 11-20cm    | Dark reddish brown     | 2,5 yr 3/3 | Clay | Very sticky | Plastic    |             |
|           |      | 21-40cm    | Dark reddish brown     | 2,5 yr 3/4 | Clay | Very sticky | Plastic    |             |
|           |      | 41-60cm    | Dark reddish brown     | 2,5 yr 3/3 | Clay | Very sticky | Plastic    |             |
|           |      | 61-100cm   | Reddish brown          | 2,5 yr 4/4 | Clay | Very sticky | Plastic    |             |
Another parameter observed was soil texture. Soil texture is soil variable (soil properties) that is always measured in environmental observations due to its relatively easy measurement and correlations to many other environmental variables. Soil with high clay content is able to retain large amounts of water [8]. Soil texture obtained from the test using finger assessment procedure [9] displays a propensity to be clay. However, the observation plot at the entrance of Curug Cilame and Bukit Pabangbon at a depth of 0-9 cm has a silty clay loam texture. The high clay content compared to sand and dust fractions in all three land uses reflects the nature of Latosol soil. In addition to that, soil consistency was also examined in the study. Soil stickiness is dominated by “very sticky” class, where soil adheres firmly to both fingers after pressure release and it stretches greatly upon separation of fingers, meaning that the tenacity is very large [7]. Based on Table 2, the plasticity increases with the depth of the soil layer.

### 3.2.2. Bulk density

Bulk density is a ratio between the weight of dry soil and soil volume obtained by ring samples. Results of soil analysis recorded the highest average soil bulk density to be found in *S. leprosula* stands with a value of 1.29 g/cm$^3$ while the lowest was in *S. selanica* stands with a value of 1.26 g/cm$^3$. The value of soil bulk density for each land use is presented in Table 3. The overall value of soil bulk density in the stands of *S. leprosula, S. selanica*, and tourism objects appeared to be nearly similar and fall into the same classification class. Variance analysis test results showed that different land uses have no significant impact on bulk density.

| Depth (cm) | Color | Munsell 2.5 YR | Texture | Consistency |
|-----------|-------|----------------|---------|-------------|
| 0-4 cm    | Dusky red | 2,5 yr 3/2 | Clay | sticky plastic |
| 5-20 cm   | Dark reddish brown | 2,5 yr 3/3 | Clay | Very sticky plastic |
| 21-40 cm  | Reddish brown | 2,5 yr 4/3 | Clay | Very sticky plastic |
| 41-60 cm  | Dark reddish brown | 2,5 yr 3/4 | Clay | Very sticky plastic |
| 61-80 cm  | Reddish brown | 2,5 yr 4/3 | Clay | Very sticky plastic |
| 81-100 cm | Reddish brown | 2,5 yr 4/4 | Clay | Very sticky plastic |

| Depth (cm) | Color | Munsell 2.5 YR | Texture | Consistency |
|-----------|-------|----------------|---------|-------------|
| 0-9 cm    | Dark reddish brown | 2,5 yr 3/4 | Silty clay loam | Rather sticky plastic |
| 10-49 cm  | Reddish brown | 2,5 yr 4/4 | Clay | Very sticky plastic |
| 50-100 cm | Red | 2,5 yr 4/6 | Clay | Very sticky plastic |
| 0-3 cm    | Very dusky red | 2,5 YR 2.5/2 | Silty clay loam | Rather sticky plastic |
| 4-20 cm   | Dusky red | 2,5 yr 3/2 | Silty clay loam | Rather sticky plastic |
| 21-40 cm  | Dark reddish brown | 2,5 yr 3/3 | Silty clay loam | Rather sticky plastic |
| 41-60 cm  | Reddish brown | 2,5 yr 4/3 | Silty clay loam | Rather sticky plastic |
| 61-100 cm | Reddish brown | 2,5 yr 4/4 | Silty clay loam | Sticky plastic |

### Table 2. Soil texture and consistency

| Depth (cm) | Color | Munsell 2.5 YR | Texture | Consistency |
|-----------|-------|----------------|---------|-------------|
| 0-3 cm    | Very dusky red | 2,5 YR 2.5/2 | Silty clay loam | Rather sticky plastic |
| 3-4 cm    | Dusky red | 2,5 yr 3/2 | Silty clay loam | Rather sticky plastic |
| 4-20 cm   | Dusky red | 2,5 yr 3/2 | Silty clay loam | Rather sticky plastic |
| 21-40 cm  | Dark reddish brown | 2,5 yr 3/3 | Silty clay loam | Rather sticky plastic |
| 41-60 cm  | Reddish brown | 2,5 yr 4/3 | Silty clay loam | Rather sticky plastic |
| 61-100 cm | Reddish brown | 2,5 yr 4/4 | Silty clay loam | Sticky plastic |

### Table 3. Soil bulk density

| Land Use        | Soil Bulk Density (g/cm$^3$) |
|-----------------|-------------------------------|
| *S. leprosula*  | 1.29                          |
| *S. selanica*   | 1.26                          |
| Tourism         | 1.27                          |

The overall value of soil bulk density in the stands of *S. leprosula, S. selanica*, and tourism objects appeared to be nearly similar and fall into the same classification class. Variance analysis test results showed that different land uses have no significant impact on bulk density.
Table 3. Soil bulk density for each land use

| Land use               | Bulk density (g/cm$^3$) | Average (g/cm$^3$) | Bulk density class |
|------------------------|-------------------------|--------------------|-------------------|
| S. leprosula stands    | 1.27                    | 1.29 a             | High              |
|                        | 1.29                    |                    |                   |
|                        | 1.32                    |                    |                   |
|                        | 1.24                    |                    |                   |
| S. selanica stands     | 1.28                    | 1.26 a             | High              |
|                        | 1.27                    |                    |                   |
|                        | 1.30                    |                    |                   |
| Tourism site           | 1.28                    | 1.28 a             | High              |
|                        | 1.27                    |                    |                   |

Remarks: Values with different alphabets indicate significant difference at (p < 0.05).

3.2.3. Total pore space

The total pore space is a part of the soil that is filled with water and air. Its values for each land use are presented in Table 4. Total pore space at all observation sites could be classified as good. Results of analysis of variance showed that differences in land use have no significant effect on total pore space.

Table 4. The total pore space value of the soil in each land use

| Land use               | Total pore space (%)* | Average (%) | Total pore space class |
|------------------------|-----------------------|-------------|------------------------|
| S. leprosula stands    | 52.07                 | 51.06 a     | Good                   |
|                        | 50.06                 |             |                        |
|                        | 53.21                 |             |                        |
| S. selanica stands     | 51.69                 | 52.32 a     | Good                   |
|                        | 52.07                 |             |                        |
|                        | 50.94                 |             |                        |
| Tourism site           | 51.44                 | 52.20 a     | Good                   |
|                        | 54.21                 |             |                        |

Remarks: Values with different alphabets indicate significant difference at (p < 0.05)

*) mineral soil particle density 2.6 g/cm$^3$

3.2.4. Water content

Results of the analysis marked the highest groundwater content to be found in tourist attractions that include Panorama Pabangbon 2, Bukit Pabangbon and Curug Cilame entrance. The average value of water content in three land uses is presented in Table 5. Groundwater content is a ratio between the weight of water contained in the soil and the weight of the dry land. Based on the results of correlation measurement between groundwater content and pF 1, 2, 2.54 and 4.2 suction matrices, it was apparent that the higher the suction matrix (pF) is given, the lower the groundwater content will be (Figure 2).

Looking at the value of water content in each pF for each type of land use, tourism objects have the highest value. Groundwater content is influenced by soil organic matter. In this study, observations on the level of organic matter were carried out by measuring litter thickness (Table 6). Results of the analysis of variance indicate that different land uses significantly affect the water content. Additionally, results of further tests also showed that the value of water content demonstrated by tourism sites was higher compared to S. selanica and S. leprosula stands (Table 5).
Table 5. Results analysis of average water content in each land use

| Land use            | Moisture content at various pF | Water content (water content) |
|---------------------|--------------------------------|-------------------------------|
|                     | pF 1   | pF 2   | pF 2, 54 | pF 4.2   |
| S. leprosula stands | 49.64 a | 48.78 a | 40.11 b  | 16.47 b  |
| S. selanica stands  | 50.77 ab| 49.12 a | 41.28 ab | 19.10 ab |
| Tourism site        | 51.61 a | 49.90 a | 42.22 a  | 21.64 a  |

Remarks: Values with different alphabets indicate significant difference at (p <0.05).

Figure 2. Graph of water content in each land use

Table 6. Litter thickness on each land use

| Land use            | Litter thickness (cm) | Average (cm) |
|---------------------|-----------------------|--------------|
| S. leprosula stands | 11.80                 | 8.22         |
|                     | 7.16                  | 5.7          |
|                     | 5.7                   | 3.38         |
| S. selanica stands  | 2.90                  | 4.67         |
|                     | 7.73                  | 1.80         |
| Tourism site        | 1.43                  | 2.46         |
|                     | 4.16                  |              |

3.2.5. Drainage pore

Drainage pore is a pore that is unable to hold water. Water in the drainage pore will automatically drain due to gravity. The pores are categorised into three groups namely overly quick drainage pores (pores that are ≥ 300 μm in size and will be empty at a pressure of 10 cm or pF 1), quick drainage pores (pores that are between 300-30 μm in size and will be empty under the pressure between 10 cm or pF 1 and 100 cm or pF 2), and slow drainage pores (pores that are between 30-9 μm in size and will be empty at a pressure of 100 cm or pF2 and a pressure of approximately 1/3 atm).
Values of quick drainage pores in all three land uses showed the highest figure in tourism objects in comparison to \textit{S. leprosula} and \textit{S. Selanica} stands (Table 7). Results of the analysis of variance indicated that different land uses significantly affect quick drainage pores. Results of further tests on quick drainage pores in three land uses showed real difference between the tourism object and those in \textit{S. Leprosula} stands, but not significantly different from those in \textit{S. selanica} stands (Table 7). The highest proportion of quick drainage pores found in tourism objects is associated with high water content in that particular land use compared to the rest (Table 4). Based on results of the analysis of variance, different land uses also significantly affect slow drainage pores. Further test results showed that slow drainage pores in three land uses varied remarkably.

**Table 7.** The results of the analysis of the average drainage pores in each land use

| Land use       | Quick drainage pores (%) | Slow drainage pores (%) |
|----------------|--------------------------|-------------------------|
| \textit{S. leprosula stands} | 3.21 a                  | 7.84 b                 |
| \textit{S. selanica stands}  | 2.29 b                  | 8.67 a                 |
| \textit{Tourism site}         | 3.51 a                  | 7.49 b                 |

Remarks: Values with different alphabets indicate significant difference at (p <0.05).

3.3.2. Permeability

Quantitative permeability can be defined as the flow of fluid through a porous medium in a saturated state. Soil permeability is closely linked to the flow rate of air and water in the soil, which depends on the amount and type of pore space, soil structure and texture. Permeable soil has to have fine continuous pores with a relatively large size for air and water movements. The average value of permeability for each land use is presented in Table 8.

**Table 8.** Average value of permeability for each land use

| Land use       | Permeability (cm/hour) | Average (cm/hour) |
|----------------|------------------------|-------------------|
| \textit{S.leprosula stands} | 1.78                   | 1.37 c            |
|                 | 1.18                   |                   |
|                 | 1.46                   |                   |
|                 | 2.30                   |                   |
| \textit{S.selanica stands} | 2.21                   | 2.13 b            |
|                 | 1.88                   |                   |
|                 | 3.33                   |                   |
| \textit{Tourism site}         | 3.47                   | 3.39 a            |
|                 | 3.63                   |                   |

Remarks: Values with different alphabets indicate significant difference at (p <0.05).

3.3. Analysis of infiltration measurement results

3.3.1. Field infiltration rate

Infiltration rate in numerous land uses varies depending on the type of land use, vegetation, as well as soil physical properties attributed to weight, porosity, texture, organic material, and drainage pore. Infiltration rate is the rate at which water enters the ground for a certain time. Correspondingly, the minimum infiltration rate or infiltration capacity refers to the rate at which water enters the ground when it reaches a constant value. Infiltration rate is determined by the amount of infiltration capacity and the rate of water supply. The average infiltration rate in this study is presented in Table 9.

Field measurement results showed the highest infiltration rate to be found in \textit{S. selanica} stands, reaching 15.5 cm/hour, followed by \textit{S. leprosula} stands with a value of 12 cm/hour, and the lowest was in tourist attraction sites with an average infiltration of 4 cm/hour. Results of the analysis of
variance tests indicated that different land uses significantly affect soil infiltration. Further test results showed that the infiltration in *S. selanica* stands was significantly different from that of tourism objects and *S. leprosula* stands (Table 9). The high infiltration rate in *S. Selanica* stands is strongly influenced by soil physical properties, which are highly porous and the presence of soil cover encompassing the undergrowth and the litter.

Based on paired sample T-test results, it was known that high infiltration in *S. Selanica* stands has a positive and fairly strong relationship, while the low infiltration rate in tourism objects points to a positive and strong relationship with litter thickness with a significance value (α <0.05), meaning that there is a correlation between the low infiltration in tourist objects and the low litter depth. Graph of infiltration rates for various land uses can be seen in Figure 3.

### Table 9. The average value of the infiltration rate for each land use

| Land use          | Infiltration rate (cm/hour) | Average (mm/hour) | Infiltration class |
|-------------------|-----------------------------|-------------------|-------------------|
| *S. leprosula* stands | 8.6                         | 12 ab             | Rather fast       |
|                   | 15                          |                   |                   |
|                   | 12.4                        |                   |                   |
|                   | 15.6                        |                   |                   |
| *S. selanica* stands | 18                         | 15,5 a            | Fast              |
|                   | 13                          |                   |                   |
|                   | 4                           |                   |                   |
| Tourism site      | 6                           | 5,1 b             | Medium            |
|                   | 5.2                         |                   |                   |

Remarks: Values with different alphabets indicate significant difference at (p <0.05).

![Figure 3](image-url)  
**Figure 3.** Graph of infiltration rates for various land uses

### 3.4. Correlations between field infiltration and Horton model and Kostiakov model

Infiltration rate is resulted from the measurement of field infiltration. Measurement results were then simplified using the infiltration model equation. Commonly used model equation to estimate infiltration rate is the empirical model which includes the *Horton* and *Kostiakov* models. The *Horton* model is an infiltration approximation model developed in order to minimise infiltration measurements and for the purposes of infiltration simulation in various field conditions, whilst the *Kostiakov* model
is an empirical model derived from field measurement data. Correlations between field infiltration and Horton and Kostiakov models can be seen in Figure 4.

Based on the Pearson's correlation test, the correlation coefficient “r” value for each land use using Horton’s equation is 0.99; 0.90; and 0.99 while Kostiakov’s showed a value of 0.05; 0.44; 0.67 (Table 10). Furthermore, significance value (Sig-2 tailed) of S. leprosula stands and tourism objects denoted significant values. On the contrary, values demonstrated by S. selanica stands were not significant, but correlation between field infiltration and Horton infiltration remains to be found. The Kostiakov infiltration model has a significant correlation with S. selanica stands and tourist attractions (Table 10).

**Figure 4.** The field infiltration regression test with Horton and Kostiakov on S. leprosula stands (a and b), S. selanica stands (c and d), tourism site (e and f).
Soil texture obtained from the sand and dust fraction. The sand fraction has a high level of organic matter content. The strong cohesiveness among its particles is largely determined by clay fraction. The state of soil physical properties in various land uses is prompted because the correlation probability value < (α) 0.05).

4. Discussion

4.1. Crown density
Crown density functions in blocking rainwater droplets to fall directly onto the ground surface. Rainwater that falls onto tree canopy flows to the stem (stem flow), some penetrate through it (throughfall) until reaching the surface of the ground and infiltrate into the soil, causing a reduced surface flow (run off) [10].

High average value of crown density in S. leprosula stands is prompted as these species have umbrella-shaped, densed canopies [11], whereas the canopy of S. selanica stands is characterized by its dangling and flat-shaped branches. On the other hand, the low crown density found through observations made in tourism sites appeared because they are dominated by pine tree species. Pine trees possess needle-like features and a pyramid-shaped canopy. This is what makes the crown density in tourist attractions was smaller than other land uses.

4.2. The state of soil physical properties in various land uses
Observation on soil physical properties was done by analysing several parameters such as soil morphology, bulk density, total pore space, water content, drainage pore and permeability. In Appendix 1 it can be seen that the upper layers have darker color than the layers below them. This is due to the higher levels of organic matter in the upper layer compared to the lower layer. The gray colour was found on the stand of S. leprosula precisely at a depth of 0-7 cm at plot number 1 which might be attributed to a condition where layer is frequently inundated by water. This also occured because plot number 1 is in situated in a basin-shaped area, causing the water to be retained on the ground.

Soil texture obtained from the test results using finger assessment procedure [9] tends to be clay. A higher clay content compared to sand and dust fractions in all three land uses reflects the character of Latosol soil. Latosol has a high level of clay distribution (equal to or more than 60%), crumbs to lumpy, with no vertical properties. Although all three land uses were dominated by the same type of soil, there are differences in their percentage of fractions. This difference is shown by the level of adhesiveness, slippage, and plasticity.

Soil stickiness was dominated by “very sticky” class, where soil adheres firmly to both fingers after pressure release and it stretches greatly upon separation of fingers, indicating a very large tenacity. The adhesiveness is strongly influenced by soil texture which was almost entirely dominated by the clay fraction. This fraction has a very strong cohesiveness among its particles, hence the adhesiveness. Another parameter is plasticity, in which the study found that the “plastic” class was dominant. Plasticity is largely determined by soil texture, the higher the clay content in the soil, the more plastic it is [7]. Based on Appendix 1, plasticity increases as soil layer deepens. It corresponds to higher clay content in deeper layer.
A high clay content causes bulk density to rise. According to Table 2, bulk density in all three land uses falls into the category of “high”. According to [8] the soil dominated by clay has high cohesiveness, thus it will increase its density. A higher density value found in S. Leprosula stands was associated to human activity above the soil surface which is marked by the pathways, causing soil pores to clog.

The percentage of total pore space was inversely proportional to its bulk density value. This finding further supports the fact that soil pores are sufficiently available and they can provide space for water or air. Besides, a low bulk density value would also indicate the development of roots and water in penetrating the soil. According to [12], a high value of total pore space in an area is inversely proportional to its bulk density value. The total pore space value in S. leprosula stands was lower than that in the tourist attractions. In fact, crown density value in S. leprosula stands was higher compared to its value in tourism sites. These findings were contrary to a research conducted by [4] who argued that soil with higher crown density makes its physical properties become healthier. A densely crown closure encourages a surge in biological activities at the soil surface, so that the number of soil pores is increasing too. The low total pore space value was allegedly caused by insignificant number of soil pores found in S. leprosula stands. It was attributed to human activities in the observation plot, where local community built pathways that affect soil compaction.

Total pore space affects the amount of water content in the soil. This is because the greater the soil’s total pore space, the greater the number of soil pores, making it more likely for soil to store larger amount of water. Soil water content is influenced by soil organic matter calculated from litter thickness. The highest level of litter thickness was found in S. leprosula stands. However, its water content was considerably lower compared to the water content found at tourism sites. Not all of the rainwater drops can directly reach the ground surface, but they are transformed in several ways, causing a reduced quantity. This transformation begins with partial retention of rainwater on the crowns, stems, leaves and twigs. Parts of the rainwater that are temporarily held on the parts of the tree are returned to the atmosphere in the form of water vapor called interception. Others flow through the stem and descend to the forest floor, known as stem flow. Meanwhile, water that falls through the crowns and spaces between them is called water escapes.

Drainage pore value is strongly influenced by water content in the soil, as this study indicated that the quick drainage pore value in tourism objects was the highest. With a higher water content, soil cohesiveness weakens, resulting in a smaller cohesiveness effect [13]. This will certainly affect soil pores to become larger. Meanwhile, slow drainage pore value was marked to reach the highest in S. selanica stands as the dominant soil texture in that stand was clay. Clay texture has many micropores due to its strong cohesive nature, enabling them to stick and bind to one another.

Another parameter of physical properties that has been observed was permeability. Based on the results of soil permeability analysis, the highest permeability index was found in tourism objects, reaching 3.39 cm/hour, while the lowest was found in S. leprosula stands, which was 1.37 cm/hour. This is because the stands of S. selanica and S. leprosula were dominated by clay texture which has plenty micropores. The micropores inhibit the movement of water and air in the soil, resulting in low permeability. High permeability index in tourism objects is caused by soil particles having lower cohesiveness due to higher water content. In addition, it is also caused by higher soil particles, characterised by a silty clay loam texture contained in those tourism areas in comparison to the other two. Another factor that influenced high permeability in tourism objects is the amount of quick drainage pore which was greater compared to other land uses (Table 6). According to [14] soil permeability index will depend on the stability of soil aggregates. Pores in a stable soil aggregate will hasten the flow of water, while pores in an unstable soil aggregate will be easily closed due to soil aggregate destruction, which in turn would inhibit water flows. The shape and amount of pores are strongly influenced by soil clay content [15].
4.3. Analysis of infiltration rate

4.3.1. Field infiltration rate
Results of field measurements highlighted that the highest infiltration rate was owned by S. selanica stands, reaching 15.5 cm/hour, followed by S. leprosula stands with a value of 12 cm/hour, and the lowest was in tourism objects with an average infiltration of 4 cm/hour. The high infiltration rate under the stands of S. selanica is strongly influenced by soil physical properties, attributed to its high porosity as well as the presence of soil cover that includes undergrowth vegetation and litter. Litter functions as temporary water storage area which will gradually releases it into the soil along with dissolved organic matter and will increase absorption capacity. In addition, the presence of undergrowth can stimulate root formation that can increase soil porosity and reduce the impact of kinestic energy of the raindrops.

Forest floor where S. selanica stands were planted was fully covered with terrestrial ferns (Gleichenia truncata). G. truncata as soil cover plant plays a role in storing the groundwater through its root system. Additionally, its fibrous root system will also improve soil porosity. This would definitely bring an impact on greater root penetration and root absorption, resulting in higher infiltration rate. According to the results of paired sample T-test, it was known that high infiltration of S. Selanica stands has a positive and fairly strong relationship (Table 9) with slow drainage pore with a value (α <0.05). However, this finding turns out to differ from [5] who argued that abundant micropores are found in soils with high cohesiveness so as to reduce infiltration rate.

The lowest infiltration rate was found in tourism objects with a rate of 51 mm/hour classified into a medium infiltration class. The low rate of infiltration in tourism object is thought to be due to lower crown density in this area compared to other land uses (Table 1). Low crown density will have an impact on high kinetic energy of the raindrop, causing soil particles to detach and consequently, compaction becomes greater. Besides, infiltration capacity was also influenced by higher water content compared to other land uses (Table 4). This is because the pore space is saturated with water, so it will prevent water from entering the soil. Based on paired sample t-test results, it is known that low infiltration in tourism objects has a positive and strong relationship with litter thickness with a value (α <0.05), meaning that there is a correlation between infiltration capacity in tourism objects and low depth of litter. Forest litter possesses an essential function to protect the soil from direct raindrops, thereby reducing surface runoff and increasing water absorption into the soil. Moreover, it also serves a function as food ingredient for soil fauna which helps loosen the soil, making it easier for water to enter the soil.

4.4. Correlations between field infiltration and Horton and Kostiakov model
Correlations between field infiltration and the Horton and Kostiakov models can be seen in Figure 4. Based on the figure, the correlation coefficient (r) of the Horton model was 0.998; 0812; and 0.997. Meanwhile, the regression coefficient value of the Kostiakov model was 0.991%; 0.686; and 0.960%. These results indicate that the correlation coefficient value using the Horton model was greater than that of the Kostiakov model, so the Horton infiltration model is considered to be able to predict the infiltration rate better in Gunung Dahu Research Forest, Bogor Regency, West Java Province.

Based on Pearson’s correlation test, the correlation coefficient “r” value for each land use using the Horton’s equation is 0.99; 0.90; and 0.99, while using Kostiakov’s it resulted in the value of 0.05; 0.44; and 0, 67 (Table 10). Furthermore, the significance value (Sig-2 tailed) of S. leprosula stands and tourism objects showed the most remarkable results. On the contrary, it does not appear to be significant in the S. selanica stands, yet there is still a correlation between field infiltration and Horton’s infiltration. Meanwhile, the Kostiakov infiltration model denotes most significant values on S. selanica stands and tourist attraction areas (Table 10). From this comparison, it can be seen that there is a strong real correlation between field infiltration and the Horton model, making the Horton model to be the most pertinent for estimating infiltration rates at all three land-use sites.
In accordance with previous study conducted by [16], it has been stated that a high correlation between the field infiltration rate and the Horton model can emphasise this method as the most plausible approach to estimate field infiltration rate in Gunung Dahu Research Forest.

5. Conclusion
Soil physical properties and infiltration rate in all three land uses have different values. The highest infiltration rate is found in S. selanica stand whilst the lowest is in the tourism object. Characteristics of the infiltration rate in Gunung Dahu Research Forest are influenced by several factors such as soil texture, porosity, type of vegetation/canopy cover, litter thickness and undergrowth, but not affected by bulk density as in infiltration rate measurement in general. The value of field infiltration rate obtained for each land use does not differ greatly from the infiltration rate of Horton model, yet on the contrary it varies greatly from the Kostiakov model. Field infiltration rate measured using Horton’s equation for each land use has higher correlation coefficient value than that of the Kostiakov model, thus the Horton model is considered to be used to estimate infiltration rate in Gunung Dahu Research Forest. To improve soil physical properties and increase the infiltration rate, especially in the area of tourist attractions, it is necessary to plant ground cover plants and to add organic materials into the soil. It is also recommended to pave particular pathways for pedestrians so that it does not disturb the ground massively.

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