Ponding time in infiltration process for different land use

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Abstract. Ponding time is the period from the beginning of rainfall/infiltration until the occurrence of ponding. This paper aims to determine the infiltration rate and ponding time on different land uses, such as open fields, residential, agriculture, and vegetation. This research was conducted in one of the watersheds in the Brantas River Basin, namely the Lesti River Basin, which is administratively included in the Malang Regency, East Java. The Lesti River is one of the tributaries of the Brantas River, which originates around Mount Semeru, a very intensive area for planting rice, sugar cane, and coffee. Infiltration data were collected at 35 points using a double-ring infiltrometer spread across the Lesti watershed with Andosol, Mediterranean, and Regosol soil types. At the same time, ponding time was obtained from infiltration measurements in the field using the flooding method. The physical properties of the soils were tested in the laboratory to obtain water content, porosity, and bulk density values. This study resulted in the infiltration rate and ponding time for each land use and shows how the physical properties of the soil affect the ponding time.

Keywords: Infiltration, ponding time, land use.

1. Introduction
The Brantas River Basin is an area with high rainfall. Heavy rain during the rainy season can cause significant flooding if no mitigation measures are taken. Rainfall, surface runoff, and infiltration are factors that contribute to flood inundation events, particularly in an urban area. Infiltration is one of the essential processes in the hydrological cycle, namely the process of seeping water from the soil surface into the soil. The amount of infiltration will affect the amount of surface runoff so that infiltration also affecting the time of saturation time and ponding time [1]. Ponding time is the time when rainwater infiltrates from the beginning of infiltration until surface runoff begins. Ponding which is a response to rain when the soil surface exceeds the soil saturation limit is undoubtedly influenced by factors that affect the infiltration rate. Soils with low infiltration capacity will cause water ponding, resulting in high surface runoff, which can cause flooding.

Many researchers have contributed to studies on the determination of infiltration rate and infiltration capacity. However, the number of studies examining ponding time and exploring the relationship among these factors is still deficient. Several studies have been carried out related to infiltration and ponding time. The factors that affect the infiltration rate are soil texture and structure, conditions on the soil
surface, soil water content, type of vegetative cover, soil temperature, land use, soil density, and biological debris [2, 3]. Ponding time is also used to estimate the amount of rain entering the ground and becoming surface runoff [4]. There is a unique relationship between ponding time and cumulative infiltration. Infiltration rate and infiltration capacity are strongly influenced by soil type, land use, and topography [5]. Changes in land use can affect the amount of surface runoff that occurs. Changes in the type of land use will reduce water infiltration and increase surface runoff, which can potentially become a flood [6]. This condition happens because the rain that falls to the ground undergoes two responses: partly infiltrating and partly flowing over the ground [7]. Infiltration is influenced by the hydraulic properties of the soil, the intensity of rainfall, and the distribution of water content with soil depth [4].

Infiltration capacity is mainly determined by the land use and the nature of the underlying soil, whether the soil is sandy or clayey. Clay has solid particles resulting in less space between the pores, thus causing a decrease in the infiltration rate. A study by [8], found that an increase in the percentage of clay has led to a decrease in soil infiltration. In addition, the physical properties of the soil also influence the amount of water that enters the soil [9]. The water content and soil moisture will cause the soil grains to expand and close the soil pores, thus reducing the infiltration rate [10]. An increase in soil water content will cause a decrease in the infiltration rate [8]. At the same time, organic material produced by vegetation can bind the water [11]. The presence of vegetation on the soil surface will increase the value of the infiltration rate [12], whereas porosity has an essential role in predicting the hydraulic properties of soil [13] since porosity can determine the ability of the soil to store groundwater so that the larger the porosity in the soil grains will increase the infiltration rate [14]. This can be seen in the difference in soil texture with a relatively high level of porosity, such as sand which can result in very fast infiltration [15]. An increase in the average grain size will increase the infiltration rate. The larger the grain shape will form the large pore shape, reducing the friction effect caused by surface tension [16,17]. This paper aims to determine the infiltration rate and ponding time on different land uses, such as open land, residential, agricultural land, and vegetated land.

2. Materials and Method

2.1. Research Location

This research was conducted in one of the watersheds in the Brantas River Basin, namely the Lesti River Basin, which is administratively located in Malang Regency, East Java. Lesti River is one of the tributaries of the Brantas River which originates around Mount Semeru with an area of 382.20 km² of watershed, which is an intensive area for plating rice, sugarcane, and coffee.

2.2. Data Collection

2.2.1. Sampling Method

The sampling point will be determined by considering the variables of soil type, land slope, and land use. The infiltration rate is influenced by several things such as land cover, soil type, and slope. Several other factors also affect the infiltration rate such as texture, water content, porosity, C-organic, permeability, and bulk density. The sampling technique used the purposive sampling method. Purposive sampling is sampling intentionally following the required sample requirements. The sample location points were selected based on the results of the overlays method for the Lesti watershed boundary map, land use maps, slope maps, and soil type maps using ArcView GIS software. The determination of the sampling point in the Lesti watershed are: soil types consist of Mediterranean, Andosol, Grumosol, and Regosol. For land use, it is divided into 4 (four) classes: Open Land, Residential, Agricultural land, and Vegetated land. Infiltration that occurs in one place is different from other places and at other times, one of which is determined by the type of land use [25]. Infiltration and soil samples were collected at 35 points, as shown in the following Figure 1.
2.2.2. Measurement of Infiltration and Soil Sampling

The data obtained are primary data which are direct observations from the field, using the Double Ring Infiltrometer which is measured directly in the field, while the ponding time is obtained from the results of infiltration measurements in the field using the flooding method. The calculation of the value of the infiltration rate is continued by the calculation of the Horton parameter ($k$) and at the same time observing the ponding time. Each parameter and related variable becomes a factor in determining the value of the infiltration rate. From the observations, the parameters of the calculation of the infiltration rate of the Horton method, consisting of $f_0$ = the initial infiltration rate, $f_c$ = constant infiltration rate, and $k$ = Horton coefficient. In addition, the ponding time ($t_p$) is also obtained.

The Horton model is one of the well-known infiltration models in hydrology. Horton acknowledges that the infiltration capacity decreases over time to a near-constant value. Horton expressed his view that the decrease in infiltration capacity is controlled by factors operating at ground level compared to the flow process in the soil. The concept used: “Infiltration starts at an initial infiltration rate value ($f_0$) and exponentially decreases until it reaches a constant infiltration rate value ($f_c$)”. Horton’s Equation in [18]:

$$f_t = f_c + (f_0 - f_c)e^{-kt}$$

for $0 \leq t \leq td$

with:
- $f_t$ = actual infiltration rate (cm/h)
- $f_c$ = constant infiltration rate (cm/h)
- $f_0$ = initial infiltration rate (cm/h) $t = 0$
- $k$ = The Horton coefficient depends on the characteristics of the soil and the land cover
- $t_d$ = rain duration

Based on the main formula, several parameters used in the use of the Horton method were determined, as follows:

a. The value $k$ of (Horton coefficient) is obtained by using the general linear equation,

$$y = mx + c$$

Figure 1. Map result from the survey location determination.
\[ y = tx = \log(f - f_c) \]  
\[ m = \frac{-1}{k \log e} \quad c = \frac{-1}{k \log e} \log(f_0 - f_c) \]  

Use this equation,

\[ m = \frac{-1}{k \log e} \quad k = \frac{-1}{m \log e} \quad \text{or} \quad k = \frac{-1}{0.4343 \times m} \]

Where \( m \) is the gradient obtained from plotting the relationship between field/actual infiltration \( f \) (cm/min) and \( \log f - f_c \) (cm/min), so that the linear regression equation \( y = mx + c \) is obtained.

b. The \( f_c \) value is obtained from the infiltration value when it reaches a steady/constant state.
c. The value of \( f_0 \) is obtained from the infiltration value when in the initial condition state.

At each sample point, soil samples are also taken for testing the physical properties of the soil. The sampling results are taken to the Soil and Groundwater Laboratory of Brawijaya University for laboratory tests, such as water content, porosity, and bulk density by conducting the water content test, specific gravity, sieve analysis, and hydrometer test.

2.3. Ponding Time

According to [19], ponding time is a term used in hydrology for a saturated soil surface (from rain) and occurs water puddle. When it rains, the water will be puddling if the intensity of the rain exceeds the value of the infiltration capacity of the soil that receives rain. Ponding time \( (t_p) \) is the time from the beginning of rainwater infiltration until surface runoff occurs, starting from the beginning of the rain occurs until the water begins to puddle on the soil surface. Time before ponding occurs \( (t < t_p) \), the intensity of rain is less than the potential rate of soil infiltration and the soil surface in unsaturated conditions. Ponding begins to occur when the intensity of rain exceeds the infiltration rate. At this time \( (t = t_p) \), the soil surface begins to saturate with water. As the rain continues \( (t > t_p) \), the soil saturated zone will deepen and the surface runoff begins to occur from the puddle.

3. Result and Discussion

3.1. Analysis of Infiltration Rates for Each Land Use

The measurement of the infiltration rate in each land use and soil type showed various results. The slope of the land does not affect the measurement results because the infiltration measurement is carried out at a point. The infiltration rate curve indicates that the value of the infiltration rate will decrease over time and will go to a constant value. In the infiltration rate curve formed two characteristics of infiltration can be known, namely, the infiltration rate that occurs at the beginning of the measurement \( (f_0) \) and constant infiltration rate that no longer changes the infiltration rate \( (f_c) \). By using Horton’s formula, it can also be known the value of the Horton coefficient \( (k) \). The ponding time \( (t_p) \) value is obtained from the measurement data in the field, which is right at the beginning when the constant infiltration rate occurs. The magnitude of \( f_0, f_c, k \) and \( t_p \) can be seen in Table 1.

The value of \( f_0 \) is the initial infiltration capacity, while \( f_c \) is the constant infiltration capacity that depends on the soil type. Parameters of \( f_0 \) and \( f_c \) are functions of soil type and cover. For sandy or gravel soils the value is high, while for bare loamy soils the value is small, and if there is grass on the soil surface the value increases. The dominant soil in this study area is sandy soil, so it has a high infiltration rate. Soil with a higher content of sand fraction and soil porosity will easily pass water so that the infiltration rate is higher. Sandy loam texture soil has a higher infiltration rate than clayey loam texture soil [20]. A studied conducted by [21] has concluded that the sequence of soil infiltration
capacity is coarse > fine > very fine > medium > medium fine, consistent with the order of the saturated hydraulic conductivity of the soil $K_s$. The value of infiltration capacity is significantly affected by the pore ratio void ratio of soil particles.

Table 1. Infiltration rate for each land use and soil type.

| Land Use     | Soil Type  | $f_0$  | $f_c$  | $k$  | $t_p$  |
|--------------|------------|--------|--------|------|--------|
|              |            | (mm/min) | (mm/min) | (1/min) | (min) |
| Open Land    | Andosol    | Max     | 8.50   | 3.50 | 0.15   | 40    |
|              | Regosol    | Min     | 4.50   | 0.55 | 0.09   | 21    |
|              | Mediterranean | Average | 6.67  | 1.75 | 0.12   | 29    |
| Agricultural | Andosol    | Max     | 17.00  | 2.50 | 0.33   | 45    |
|              | Regosol    | Min     | 4.00   | 0.60 | 0.09   | 16    |
|              | Mediterranean | Average | 10.25 | 1.81 | 0.17   | 34    |
| Vegetation   | Andosol    | Max     | 16.50  | 5.25 | 0.30   | 35    |
|              | Regosol    | Min     | 2.00   | 1.00 | 0.06   | 16    |
|              | Mediterranean | Average | 6.83  | 2.62 | 0.18   | 25    |
| Residential  | Andosol    | Max     | 12.50  | 4.50 | 0.18   | 20    |
|              | Regosol    | Min     | 5.00   | 2.00 | 0.13   | 18    |
|              | Mediterranean | Average | 9.17  | 3.17 | 0.16   | 19    |
|              | Andosol    | Max     | 6.00   | 1.50 | 0.57   | 14    |
|              | Regosol    | Min     | 1.50   | 0.25 | 0.12   | 9     |
|              | Mediterranean | Average | 3.83  | 1.00 | 0.37   | 12    |
|              | Andosol    | Max     | 15.00  | 5.00 | 0.29   | 12    |
|              | Regosol    | Min     | 15.00  | 5.00 | 0.29   | 12    |
|              | Mediterranean | Average | 15.00 | 5.00 | 0.29   | 12    |
|              | Andosol    | Max     | 11.00  | 5.50 | 0.22   | 75    |
|              | Regosol    | Min     | 4.00   | 0.50 | 0.08   | 11    |
|              | Mediterranean | Average | 6.67  | 2.42 | 0.13   | 33    |
|              | Andosol    | Max     | 11.00  | 4.50 | 0.28   | 13    |
|              | Regosol    | Min     | 0.33   | 0.10 | 0.26   | 7     |
|              | Mediterranean | Average | 5.67  | 2.30 | 0.27   | 10    |
|              | Andosol    | Max     | 17.00  | 3.60 | 0.29   | 75    |
|              | Regosol    | Min     | 8.00   | 1.00 | 0.06   | 20    |
|              | Mediterranean | Average | 11.67 | 2.37 | 0.17   | 43    |

The test results show that the highest initial infiltration rate ($f_0$) is found in vegetation with Mediterranean soil type amounted to 15.00 mm/minute and the lowest initial infiltration rate ($f_0$) is found in vegetation with regosol soil type equal to 3.83 mm/minute. For the highest constant infiltration rate ($f_c$) was found in the vegetation with Mediterranean soil type amounted to 5.00 mm/minute and the lowest constant infiltration rate ($f_c$) was found in the vegetation with regosol soil type equal to 1.00 mm/minute. The highest Horton coefficient value ($k$) is found in vegetation with regosol soil type 0.37/min and the lowest $k$ value is found in open land with Mediterranean soil type of 0.02/min. The highest ponding time ($t_p$) value is found in residential with Mediterranean soil type namely equal to 43.
minutes and the lowest ponding time (\(t_p\)) value is found in open land with Mediterranean soil type namely amounted to 6 minutes.

3.2. Analysis of Soil Physical Properties on each land use
From the results of laboratory tests, it was found that each land use has different values of water content, porosity, and bulk density, as shown in Table 2.

| Land Use      | Soil Types | Physical Parameters | Water Content (% | Porosity (%) | Bulk Density (gram/cm\(^3\)) |
|---------------|------------|---------------------|-----------------|-------------|-----------------------------|
| Open Land     | Andosol    |                     | 51.86           | 58.02       | 1.17                        |
|               | Regosol    |                     | 59.27           | 50.19       | 1.14                        |
|               | Mediterranean |                 | 15.26           | 43.75       | 1.61                        |
| Agricultural  | Andosol    |                     | 38.64           | 48.83       | 1.35                        |
|               | Regosol    |                     | 99.87           | 61.50       | 1.01                        |
|               | Mediterranean |             | 42.99           | 47.33       | 1.34                        |
| Vegetation    | Andosol    |                     | 136.49          | 69.65       | 0.68                        |
|               | Regosol    |                     | 72.94           | 52.71       | 1.10                        |
|               | Mediterranean |             | 56.34           | 47.46       | 1.41                        |
| Residential   | Andosol    |                     | 67.99           | 59.15       | 1.15                        |
|               | Regosol    |                     | 46.96           | 52.01       | 1.13                        |
|               | Mediterranean |             | 35.00           | 48.15       | 1.43                        |

The test results show that the highest water content value is found in the vegetation with Andosol soil type amounted to 136.49% and the lowest water content value is found in open land with Mediterranean soil type equal to 15.26%. The high value of water content in vegetation is that there are still water reserves in the soil when it rains, and on forest land, the evaporation process is also slow with the existing land cover. The highest porosity value was found in vegetation with andosol soil type vegetation equal to 69.65% and the lowest porosity value was found in open land with Mediterranean soil type amounted to 43.75%. [20] states that the thickness of plant litter will increase the activity of microorganisms in the soil, directly or indirectly affecting the infiltration rate due to increased soil porosity. The highest bulk density value is found in open land with a Mediterranean soil type of 1.61 gr/cm\(^3\). The lowest bulk density value is found in vegetation with Andosol soil type of 0.68 gr/cm\(^3\). Bulk density values are very sensitive to land use, good land use can reduce bulk density and destroy structures but poor land use can increase bulk density [22]. The high bulk density value indicates that the organic matter content is low since the denser a certain soil so that it is more difficult for water to enter it or called low infiltration [23]. According to [24], bulk density is an indication of soil density. The denser the soil, the higher the bulk density, which means it is more difficult to pass water or penetrated by plant roots.

3.3. Relationship of Constant Infiltration Rate with Physical Properties of Soil
Soil characteristics, including density and porosity, determine infiltration rate. Meanwhile, infiltration rate and infiltration capacity are influenced by soil texture, soil structure, permeability, soil absorption, vegetation type, and land slope. The high ability of soil to pass water is also influenced by low water content because the pore space is not saturated with water so that water can enter the soil, while the water-saturated soil will not provide an opportunity for water to enter the soil [20]. Normally, the condition of saturated soil (soil with high water content) shows a lower infiltration rate than unsaturated soil [25]. The constant infiltration rate values for each land use and soil type are presented in Figure 2.
From the figure above, it can be seen that the \( f_c \) value from the highest to the lowest respectively is found in the vegetation with Mediterranean soil type amounted to 5 mm/minute, then on the open land with Mediterranean soil type equal to 4 mm/minute, then in agriculture with the regosol soil type amounted to 2.62 mm/minute and the last one in residential with Andosol soil type equal to 2.42 mm/minute. The sequence of constant infiltration rate starts from the highest, namely 1) vegetation overgrown with pine, coffee, teak, rubber 2) Open land in this case in the form of grass and shrubs, 3) agriculture in the form of seasonal crops such as corn, sugar cane, chili, 4) residential. The results of this analysis are slightly different from [26] who stated that the order of the average infiltration rate from highest is 1) shrubs, 2) dry fields, 3) plantations, 4) vacant land, 5) settlements, 6) irrigated rice fields. According to Cook in [27] the infiltration rate of the seasonal crops is lower than grass.

Vegetation has the highest constant infiltration rate because the roots of pine, coffee, teak, rubber are more abundant and scattered, which also helps the soil to become more hollow so that more water absorption. The presence of plants can increase the soil's infiltration capacity due to an improvement in the physical properties of the soil, such as the formation of structures and an increase in porosity. Land use for shrubs has a high infiltration rate. This can be influenced by a variety of vegetation that grows on the surface of the soil and has fibrous roots so that it helps the process of water absorption. The higher the density of plant roots, the better the physical condition of the soil, this is due to good aeration. Fibrous roots in shrubs make the soil texture more crumbly and porous.

**Table 3.** Constant infiltration rate and soil physical properties in each land use and soil type.

| Land Use  | Soil Type | \( f_c \) (mm/minute) | Water Content (%) | Porosity (%) | Bulk Density (g/cm\(^2\)) |
|-----------|-----------|----------------------|-------------------|--------------|--------------------------|
| Open Land | Andosol   | 1.75                 | 51.86             | 58.02        | 1.17                     |
|           | Regosol   | 2.50                 | 59.27             | 50.19        | 1.14                     |
|           | Mediterranean | 4.00            | 15.26             | 43.75        | 1.61                     |
| Agricultural | Andosol | 1.81                 | 38.64             | 48.83        | 1.35                     |
|           | Regosol   | 2.62                 | 99.87             | 61.50        | 1.01                     |
|           | Mediterranean | 2.50            | 42.99             | 47.33        | 1.34                     |
| Vegetation | Andosol | 3.17                 | 136.49            | 69.65        | 0.68                     |
|           | Regosol   | 1.00                 | 72.94             | 52.71        | 1.10                     |
|           | Mediterranean | 5.00            | 56.34             | 47.46        | 1.41                     |
| Residential | Andosol | 2.42                 | 67.99             | 59.15        | 1.15                     |
|           | Regosol   | 2.30                 | 46.96             | 52.01        | 1.13                     |
|           | Mediterranean | 2.37            | 35.00             | 48.15        | 1.43                     |
The constant infiltration rate values and soil physical properties for each land use and soil type are presented in Table 3.

3.3.1. Open Land
Based on the results of infiltration measurements in the field and testing of soil physical properties in the laboratory, the highest constant infiltration value in open land was found in Mediterranean soil types of 4.00 mm/min. In open land, the soil Mediterranean type has the lowest water content value of 15.26% and also has the lowest porosity value of 43.75%. On the other hand, the Mediterranean soil type in open land has the highest bulk density value of 1.61 gr/cm³.

3.3.2. Agriculture
Based on the results of infiltration measurements in the field and testing of soil physical properties in the laboratory, the highest constant infiltration value in agriculture was found in the regosol soil type of 2.62 mm/min. In agriculture, regosol soil type has the highest water content value of 99.87% and also has the highest porosity value of 61.50%. On the other hand, regosol soil type has the lowest bulk density value of 1.01 gr/cm³.

3.3.3. Vegetation
Based on the results of infiltration measurements in the field and testing of soil physical properties in the laboratory, the highest constant infiltration value in vegetation was found in Mediterranean soil types of 5.00 mm/min. In vegetation, Mediterranean soil type has the lowest water content value of 56.34% and also has the lowest porosity value of 47.46%. On the other hand, vegetation with Mediterranean soil type has the highest bulk density value, namely amounted to 1.41 gr/cm³.

3.3.4. Residential
Based on the results of infiltration measurements in the field and testing of soil physical properties in the laboratory, the highest constant infiltration value in residential was found in the andosol soil type of 2.42 mm/min. In residential, Andosol soil type has the highest water content value of 67.99% and also has the highest porosity value of 59.15%. On the other hand, the Andosol soil type has a low bulk density value of 1.15 gr/cm³.

[22] states that the infiltration rate is inversely related to bulk density and soil water content. So that the higher the bulk density and soil water content, the lower the infiltration rate. Infiltration rate is directly proportional to porosity and permeability. Thus, the higher the porosity and permeability, the higher the infiltration rate. The relationship between constant infiltration and soil density is inversely proportional. Constant infiltration rate with soil porosity, soil water content, and organic matter directly proportional. This is consistent with constant infiltration in agriculture and residential where a high infiltration rate value is directly proportional to high water content and porosity value, but inversely proportional to a low bulk density value. This condition occurs in andosol and regosol soil types. However, this does not occur in open land and vegetation, where a high infiltration rate value is inversely proportional to the low water content and porosity values but is directly proportional to the high bulk density value. This condition occurs in Mediterranean soil types.

3.4. Relationship of Ponding Time with Soil Physical Properties
From the observations of ponding time based on infiltration measurement data in the field, different ponding time values were obtained for each land use, as shown in Figure 3.

From the figure above, it can be seen that the ponding time value respectively from the highest to lowest is found in the residential with Mediterranean soil type amounted to 43 minutes, then in agriculture with Andosol soil type amounted to 34 minutes, then in the open land with Andosol soil type equal to 29 minutes and the last one in vegetation with Andosol soil type equal to 19 minutes. The order of ponding time starts from the highest, namely 1) residential, 2) agriculture in the form of seasonal crops such as corn, sugar cane, chili, 3) Open land in this case in the form of grass and shrubs, 4)
vegetation overgrown with pine, coffee, teak, rubber. This is inversely proportional to the value of the constant infiltration rate for each land use.

![Ponding Time On Different Land Use](image)

**Figure 3.** Ponding time on each land use and soil type.

The value of ponding time and soil physical properties for each land use and soil type is presented in Table 4.

| Land Use   | Soil Type   | Ponding Time | Water Content | Porosity   | Bulk Density |
|------------|-------------|--------------|---------------|------------|--------------|
| Open Land  | Andosol     | 29           | 51.86         | 58.02      | 1.17         |
|            | Regosol     | 18           | 59.27         | 50.19      | 1.14         |
|            | Mediterranean | 6          | 15.26         | 43.75      | 1.61         |
| Agricultural | Andosol     | 34           | 38.64         | 48.83      | 1.35         |
|            | Regosol     | 25           | 99.87         | 61.50      | 1.01         |
|            | Mediterranean | 16        | 42.99         | 47.33      | 1.34         |
| Vegetation | Andosol     | 19           | 136.49        | 69.65      | 0.68         |
|            | Regosol     | 12           | 72.94         | 52.71      | 1.10         |
|            | Mediterranean | 12       | 56.34         | 47.46      | 1.41         |
| Residential | Andosol     | 33           | 67.99         | 59.15      | 1.15         |
|            | Regosol     | 10           | 46.96         | 52.01      | 1.13         |
|            | Mediterranean | 43       | 35.00         | 48.15      | 1.43         |

### 3.4.1 Open Land

Based on the results of infiltration measurements in the field and testing of soil physical properties in the laboratory, the highest ponding time value in open land was found in Andosol soil type of 29 minutes. In open land, Andosol soil type has the highest porosity value of 58.02% and also has a high water content value namely amounted to 51.86%. On the other hand, in open land, the andosol soil type has a low bulk density value namely equal to 1.17 gr/cm³.

### 3.4.2 Agriculture

Based on the results of infiltration measurements in the field and testing of soil physical properties in the laboratory, the highest ponding time value in agriculture was found in Andosol soil type of 4.00 minutes. In agriculture, Andosol soil type has the lowest water content value of 38.64% and also has a low porosity value of 48.83%. On the other hand, the Andosol soil type has the highest bulk density value, namely 1.35 gr/cm³.
3.4.3 Vegetation
Based on the results of infiltration measurements in the field and testing of soil physical properties in the laboratory, the highest ponding time value for vegetation was found in Andosol soil type of 19 minutes. In vegetation, Andosol soil type has the highest porosity value of 69.65% and also has the highest water content value of 136.49%. On the other hand, Andosol soil type vegetation has the lowest bulk density value of 0.68 gr/cm$^3$.

3.4.4. Residential
Based on the results of infiltration measurements in the field and testing of soil physical properties in the laboratory, the highest ponding time value in residential was found in Mediterranean soil types of 43 minutes. In residential, Mediterranean soil type has the lowest water content value of 35.00% and also has the lowest porosity value of 48.15%. On the other hand, in the residential, Mediterranean soil type has the highest bulk density value, namely 1.43 gr/cm$^3$. The low water content causes the high ponding time values, plus the soil conditions tend to be denser in residential. This is because in residential there may have been compaction by several factors, such as compaction by people or animals, and can also be caused by rainwater blows so that the possibility of microorganism activity is very low. Suppose the density of the soil is high. In that case, the pore space will be less so that it is difficult for air and water to move in the soil and the porosity of the soil decreases so that the infiltration rate becomes low [28]. The infiltration rate is very low and takes longer to infiltrate into the soil. This condition is caused by soil conditions where the topsoil consists of compact soil, causing less vacuum space between soil particles. This shows that the infiltration capacity is significantly affected by the soil type and the behavior of the topsoil.

In open land and vegetation, the high ponding time values are directly proportional to high water content and porosity values, but inversely proportional to low bulk density values. This condition occurs in andosol soil types. However, this does not occur in agriculture and residential, where high ponding time values are inversely proportional to low water content and porosity values, but directly proportional to high bulk density values. This condition occurs in Andosol and Mediterranean soil types.

4. Conclusion
The value of the highest constant infiltration rate for each land use is inversely proportional to the highest value of ponding time for each land use. The constant infiltration rate ($f_c$) and ponding time ($t_p$) values are strongly influenced by parameters of soil physical properties such as water content, porosity and bulk density. The value of constant infiltration in agriculture and residential is directly proportional to water content and porosity but inversely proportional to bulk density. On the other hand, in open land and vegetation, the value of infiltration rate is inversely proportional to the value of water content and porosity but directly proportional to the value of bulk density. In open land and vegetation, the value of ponding time is directly proportional to the value of water content and porosity, but inversely proportional to the value of bulk density. On the other hand, in agriculture and residential, ponding time is inversely proportional to the value of water content and porosity, but directly proportional to the value of bulk density. In the future, it is necessary to analyze soil permeability which is also a factor that affects the infiltration rate, so that the relationship between soil permeability and the value of constant infiltration rate ($f_c$) and the value of ponding time ($t_p$) is obtained.

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