Assessment of infiltration rate in the Lawe Menggamat Sub-Watershed, Aceh Province, Indonesia

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Abstract. The Lawe Manggamat sub-watershed has been degraded as indicated by the increasing frequency of flood events from year to year. This is related to the hampered infiltration process so that the volume of rainfall that enters the soil is getting smaller, on the other hand, the surface runoff tends to increase. This study aimed to determine the infiltration rate in the Lawe Menggamat sub-watershed, Aceh Province, Indonesia. This research uses a descriptive method (survey) which refers to the Land Map Unit (LMU) by considering the type of land use, soil type, and slope. Infiltration in the field was observed using a double-ring infiltrometer at 17 LMU. The results showed that the infiltration rate in the Lawe Menggamat sub-watershed consisted of 5 categories, namely: fast (LMU-1, LMU-8, and LMU-16), rather fast (LMU-2, LMU-3, and LMU-17), medium (LMU-6, LMU-7, and LMU-10), rather slow (LMU-4, LMU-5, LMU-9, LMU-11, and LMU-15), slow (LMU-12, LMU-13, and LMU-14). The dominant factors affecting the infiltration rate are texture, C-organic, bulk density, soil type, and land use. Management of cover crops and organic matter, as well as forest and land rehabilitation, are expected to improve infiltration in these areas.

1. Introduction
A watershed is an ecosystem with the main components of vegetation, soil, water and humans. A watershed can have biophysical conditions such as various types of use, soil types, topography, rainfall, geology, geomorphology, and humans, which are different from other watersheds. The biophysical characteristics of this watershed can be a driving factor for the decline in the condition of a watershed. The condition of many watersheds in Aceh has suffered serious degradation. This is indicated by the increasing frequency of flooding. The condition of the Lawe Menggamat sub-watershed has been degraded, as indicated by the occurrence of flooding in the Lawe Menggamat Sub-watershed on 29 December 2017, 20 March 2018, and 1 April 2018. One of the factors that causes flooding is the obstruction of infiltration. Infiltration is the process of entering water into the soil vertically. Conversely, the obstruction of infiltration can cause an increase in surface runoff which increases the frequency of flood events.

Many factors determine the infiltration rate. Different types of land use, for example, provide different infiltration responses. One type of land use can play a role in accelerating the infiltration rate but another type of land use may inhibit it. Likewise, a soil type that has a certain texture will respond differently to the infiltration rate with other soil types.

Many researchers have reported infiltration studies in various models and field conditions. Infiltration research on various models such as Kostiakov, Modified Kostiakov, and US-Soil
Conservation Service (SCS), Philip, Horton [1], [2], the effect of changing infiltration rates on the runoff process in urban areas [3], and spatial analysis of infiltration on agricultural land in an arid area [4]. However, research related to infiltration and the factors that influence it based on the Land Map Unit (LMU), especially in the Sub-watershed of Lawe Menggamat, has never been carried out. Several factors that are thought to affect infiltration such as texture, C-organic, aggregate stability, porosity, bulk density, permeability, soil type, and land use have never been studied in this area. Therefore, the research to determine the infiltration rate and its influencing factors in the Lawe Menggamat Sub-watershed, Aceh Province, Indonesia, was very important to be carried out.

2. Materials and methods
This research was conducted from February to July 2019, which is located in the Lawe Menggamat Sub-watershed, Aceh Province, Indonesia. The method used in this study was descriptive (survey) with field observations, measuring the infiltration rate using a double-ring infiltrometer. Field observations were also carried out on several parameters such as soil structure, tillage, and vegetation cover. Furthermore, laboratory analyzes for some parameters such as soil texture, C-organic, porosity, bulk density, permeability had been carried out at the Laboratory of Soil Physics and Soil Chemistry, Faculty of Agriculture, Syiah Kuala University.

The Land Map Unit (LMU) was used to determine the location points of the infiltration measurement. The process of creating an LMU conducted using the ArcGis application by overlapping maps of soil types, slope, and land use. The overlay results obtained 17 LMUs as presented in Table 1 and the location of each LMU can be seen in Figure 1.

| LMU  | Land use type     | Topography | Soil type | Area (ha) |
|------|-------------------|------------|-----------|-----------|
| LMU-1| Protected forest  | 25-45%     | Entisol   | 200.98    |
| LMU-2| Protected forest  | 15-25%     | Ultisol   | 533.23    |
| LMU-3| Protected forest  | 25-45%     | Ultisol   | 436.30    |
| LMU-4| Plantation        | 8-15%      | Inceptisol| 25.71     |
| LMU-5| Plantation        | >45%       | Inceptisol| 9.27      |
| LMU-6| Plantation        | 15-25%     | Entisol   | 643.72    |
| LMU-7| Plantation        | 25-45%     | Entisol   | 361.38    |
| LMU-8| Plantation        | >45%       | Entisol   | 185.27    |
| LMU-9| Plantation        | 8-15%      | Ultisol   | 440.43    |
| LMU-10| Plantation       | 25-45%     | Ultisol   | 679.34    |
| LMU-11| Settlement       | 0-8%       | Inceptisol| 72.45     |
| LMU-12| Settlement       | 8-15%      | Inceptisol| 1.24      |
| LMU-13| Settlement       | 0-8%       | Ultisol   | 37.67     |
| LMU-14| Lowland agriculture | 0-8%     | Inceptisol| 329.73    |
| LMU-15| Upland agriculture | 15-25%   | Inceptisol| 186.60    |
| LMU-16| Upland agriculture | 25-45%   | Entisol   | 211.83    |
| LMU-17| Upland agriculture | 8-15%    | Ultisol   | 617.10    |

Total 4,972.25
Figure 1. Land Map Unit (LMU) in Lawe Menggamat Sub-Watershed.

The infiltration rate (cm hour$^{-1}$) was analyzed using the Horton formula [5] as follows.

$$f = fc + (f0 - fc)e^{-kt} \ldots \quad (1)$$

Where, $f =$ infiltration capacity at time $t$ (cm hour$^{-1}$), $fc =$ amount of infiltration at constant time (cm hour$^{-1}$), $f0 =$ amount of infiltration at initial time (cm hour$^{-1}$), $k =$ constant, $t =$ time (hour), and $e = 2.7183$.

Furthermore, the infiltration rate values for each LMU were classified using the criteria as listed in Table 2 [6].

| Class | Criteria        | Infiltration rate (mm/jam) |
|-------|-----------------|----------------------------|
| 0     | Very slow       | < 1                        |
| 1     | Slow            | 1 – 5                      |
| 2     | Rather slow     | 5 – 20                     |
| 3     | Medium          | 20 - 65                    |
| 4     | Rather fast     | 65 - 125                   |
| 5     | Fast            | 125 - 250                  |
| 6     | Very fast       | >250                       |

Various soil characteristics that influence the infiltration rate were analyzed in the field and the laboratory. The parameters and methods of analysis of the factors that affect the infiltration rate can be seen in Table 3.
Table 3. The parameters and methods of analysis.

| No | Parameters               | Method                           |
|----|--------------------------|----------------------------------|
| 1  | Texture                  | Pipette Method                   |
| 2  | C-Organic                | Walkley and Black                |
| 3  | Aggregate stability      | Dry and wet sieving              |
| 4  | Bulk Density (BD)        | Ring Sample (Core Method)        |
| 5  | Porosity                 | Ring Sample (Water content measurement) |
| 6  | Permeability             | Ring Sample (Volumetric)         |
| 7  | Soil type                | Soil map analysis                |
| 8  | Land use type            | Field observation                |

3. Results and discussion

3.1. Infiltration rate

The results of the analysis of the infiltration rate in the Lawe Menggamat sub-watershed based on the Land Map Unit (LMU) using the Horton method can be seen in Table 4 and the map of the infiltration class is shown in Figure 2. The infiltration rate classes found in the field consisted of 5 classes, namely fast, rather fast, medium, rather slow, and slow which were distributed throughout the Lawe Menggamat sub-watershed. However, there was not found very slow and very fast infiltration class in this area.

The fast infiltration classes were found in LMU-1, LMU-8, and LMU-16 with infiltration rates of 155-167 mm hour$^{-1}$. The rather fast infiltration rate classes were found in LMU-2, LMU-3, and LMU-17 with infiltration rates ranging from 113 to 119 mm hour$^{-1}$. Medium infiltration rate classes were found at LMU-6, LMU-7, and LMU-10 with infiltration rates of 21-27 mm hour$^{-1}$. Rather slow infiltration rate classes were found at LMU-4, LMU-5, LMU-9, LMU-11, and LMU-15 with infiltration rates of 12-20 mm hour$^{-1}$. The slow infiltration rate classes were found at LMU-12, LMU-13, and LMU-14 with infiltration rates of 1-4 mm hour$^{-1}$.

Table 4. Infiltration rate in Lawe Menggamat Sub-Watershed.

| Number of LMU | Infiltration rate (mm hour$^{-1}$) | Class | Criteria  |
|---------------|------------------------------------|-------|-----------|
| LMU-1         | 155                                | 5     | Fast      |
| LMU-2         | 113                                | 4     | Rather fast |
| LMU-3         | 114                                | 4     | Rather fast |
| LMU-4         | 17                                 | 2     | Rather slow |
| LMU-5         | 20                                 | 2     | Rather slow |
| LMU-6         | 21                                 | 3     | Medium    |
| LMU-7         | 23                                 | 3     | Medium    |
| LMU-8         | 167                                | 5     | Fast      |
| LMU-9         | 19                                 | 2     | Rather slow |
| LMU-10        | 27                                 | 3     | Medium    |
| LMU-11        | 12                                 | 2     | Rather slow |
| LMU-12        | 1                                  | 1     | Slow      |
| LMU-13        | 4                                  | 1     | Slow      |
| LMU-14        | 4                                  | 1     | Slow      |
| LMU-15        | 17                                 | 2     | Rather slow |
| LMU-16        | 167                                | 5     | Fast      |
| LMU-17        | 119                                | 4     | Rather fast |
3.2. Factors affecting infiltration

The factors that affect the infiltration for each LMU in the Lawe Menggamat sub-watershed can be seen in Table 5. Soil texture affects the infiltration rate. Some LMUs which have a predominantly sand and silt show a rather fast and fast infiltration rate, vice versa for LMUs which have clay show a slow and rather slow infiltration class. Meanwhile, the LMUs which have a loam texture show a medium infiltration class. There are 9 LMUs whose infiltration is influenced by soil texture. Likewise, other factors have specific effects on several LMUs observed. Aggregate stability factors influenced infiltration at all LMUs, followed by C-Organic, land use type, and soil type.

Table 5. Factors affecting infiltration for each LMU.

| No | Factors affecting infiltration | Number of LMU |
|----|--------------------------------|---------------|
| 1  | Texture                        | LMU-1, LMU-2, LMU-3, LMU-5, LMU-8, LMU-9, LMU-13, LMU-14, and LMU-17 |
| 2  | C-Organic                      | LMU-1, LMU-6, LMU-7, LMU-8, LMU-10, LMU-11, LMU-12, LMU-13, LMU-14, LMU-15, LMU-16, and LMU-17 |
| 3  | Aggregate stability            | LMU-1, LMU-2, LMU-3, LMU-4, LMU-5, LMU-6, LMU-7, LMU-8, LMU-9, LMU-10, LMU-11, LMU-12, LMU-13, LMU-14, LMU-15, LMU-16, and LMU-17 |
| 4  | Porosity                       | LMU-1, LMU-2, LMU-6, LMU-7, LMU-8, LMU-16, and LMU-17 |
| 5  | Bulk Density                   | LMU-4, LMU-5, LMU-9, LMU-11, LMU-12, LMU-13, and LMU-15 |
| 6  | Permeability                    | LMU-3, LMU-4, LMU-5, LMU-6, LMU-7, LMU-11, and LMU-14 |
| 7  | Soil type                      | LMU-1, LMU-4, LMU-5, LMU-6, LMU-7, LMU-8, LMU-9, LMU-3, and LMU-14 |
3.2.1. Texture. Soil physical properties that predominantly affect infiltration is texture. A clay texture has a lower infiltration than a sandy texture. The more the percentage of sand in a soil, the greater the water that is released by the soil because the sand fraction has a greater infiltration capacity compared to the clay fraction [7, 8]. Clay content is the most influential factor across all the soils [9].

3.2.2. C-Organic. The higher the organic matter of a land where there is a lot of litter covering the soil surface and the presence of ground cover plants will increase the activity of microorganisms in decomposing organic matter which will maintain the soil structure, while areas without litter are likely to harden and form a crust due to high surface flow [10]. Generally, organic matter reduced these peak values for all the soils at all compaction levels the effect of organic matter on the strength properties of compacted agricultural soils depends on the level of soil moisture at compaction and the type of organic material [11]. The experimental results showed that soil organic materials can enhance soil water contents within low suctions and saturated infiltration rates by virtue of improvement of soil structure and increasing porosity. The establishment of quantitative functions can provide a help for the regional experience forest-hydrological model research [12].

3.2.3. Aggregates stability. Aggregates can create a favorable physical environment for plant root development. Soil aggregates that are less stable when exposed to disturbance will easily be broken. The crushed fine grains will block the soil pores so that the bulk density increases, aeration is poor and permeability becomes slow. The stability of aggregates also greatly determines the level of soil sensitivity to erosion [13]. Soil which has a stable aggregate is not prone to compacting. The infiltration rate decreased with an increase in the bulk density and a decrease in the porosity. The volume of macropores had a significant effect on the infiltration rate [14].

3.2.4. Porosity. The infiltration rate is inversely proportional to porosity, where the greater the total porosity, the smaller the infiltration rate, and vice versa [6, 7, 8]. In this case, the presence of macropores within the soil can function as a small channel which increases the infiltration capacity [15]. The decrease in the air-filled porosity can be caused by increased compacting [14]. Organic amendments can increase porosity and infiltration rate [16].

3.2.5. Bulk density. Bulk density is an indicator of soil density. The denser the soil, the higher the bulk density which makes it more difficult for water to pass or penetrate plant roots. The lower rate of soil infiltration is the effect of reduced macro pores, vice versa for micro pores. The increase in bulk density in urban areas is more influenced by compacting. The infiltration rate decreases with increasing bulk density [14, 17].

3.2.6. Permeability. Pore size and the relationship between pores determine whether the soil has low or high permeability. The permeability may also be close to zero if the soil pores are very small, such as in soils that have a high clay content [6, 5, 8, 9]. Soil with fast permeability will increase the rate of water infiltration into the soil thereby reducing runoff at the soil surface [18].

3.2.7. Soil type. There are 3 types of soil found in this location, namely Entisols, Inceptisols, and Ultisols. Entisol is a newly developed soil. Strong erosion can cause more material to be degraded than was formed by the soil formation process. Entisols are found on steep slopes [19]. Soils that are prone to erosion have less stable soil structures and are more prone to erosion than those with stable structures [20]. Inceptisol is immature soil with a weak profile development, and much resembles its parent material [19]. Ultisols generally have high clay content which can cause problems such as water retention and transmission, soil compaction, and root penetration. The unbalanced pore distribution,
because it is dominated by micropores, causes poor aeration, low infiltration rate, and is sensitive to erosion. Furthermore, aggregate stability and soil permeability are also low due to the low organic matter content [21]. Crumb soil will provide a greater infiltration capacity than clay [22]. Soil water infiltration is an important process whose behavior depends on external factors and soil properties, which vary depending on the type of soil. Various types of soil have different infiltration rates which are influenced by texture, bulk density, and structural stability [9].

3.2.8. Land use type. Vegetation and land use practices have a marked effect on infiltration. Some practices, such as no-tillage (conservation tillage), are used to increase water movement into the soil [23]. Good surface cover conditions, such as cover crops, which inhibit surface runoff and reduce compaction due to raindrops, can increase infiltration. Protecting soil from raindrops with cover crops can protect soil pores from clogging as well as the resulting litter which causes the infiltration rate to increase [24]. Forests have a very important role in controlling the amount of surface runoff and infiltration. The infiltration rate on deforested soil is very low when compared to forests with cover crops. Open soils tend to have lower infiltration rates than land with cover crops [25, 26].

4. Conclusion
The results showed that the infiltration rate in the Lawe Menggamat sub-watershed consisted of 5 categories, namely: fast, rather fast, medium, rather slow, and slow. However, there is no very slow and very fast infiltration rate at this location. Fast infiltration rates (155-167 mm hour$^{-1}$) were found in LMU-1, LMU-8, and LMU-16. Rather fast infiltration rates (113 to 119 mm hour$^{-1}$) were found in LMU-2, LMU-3, and LMU-17. Medium infiltration rates (21-27 mm hour$^{-1}$) were found in LMU-6, LMU-7, and LMU-10. Rather slow infiltration rates (12-20 mm hour$^{-1}$) were found in LMU-4, LMU-5, LMU-9, LMU-11, and LMU-15. Slow infiltration rates (1-4 mm hour$^{-1}$) were found in LMU-12, LMU-13, and LMU-14. The dominant factors affecting the infiltration rate are texture, C-organic, bulk density, soil type, and land use. Management of cover crops and organic matter, as well as forest and land rehabilitation, are expected to increase infiltration in the area.

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