The study of soil infiltration in west part of Semarang City, Indonesia

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Abstract. This research examined the types and characteristics of soil, including the porosity, the water content, the void ratio, and the degree of saturation to the value of the infiltration rate in the soil located in the western part of Semarang City, Indonesia. The infiltration rate test was carried out at 49 measurement points, based on a 2×2 km^2 grid division in the research area. The infiltration rate measurement in the field was carried out using a turf-tech infiltrometer. The data from the infiltration rate measurement results in the field were calculated using the infiltration rate estimation model from Kostiakov, which was further classified by the Konhke classification. The results of the infiltration rate measurement showed that the research area had infiltration rate values that varied, from very slow to very fast, with the values ranged from 0 mm/hour to 1601.33 mm/hour. The analysis results showed that the type of soil, the water content, the degree of saturation, and the porosity related to the infiltration rate in the research area. The soil type parameter had the smallest relationship to the infiltration rate with the R^2 value of 0.2923. The soil porosity had the largest relationship to the infiltration rate in the research area, with an R^2 value of 0.4854.

1 Introduction

Infiltration is one of the main components in the hydrological cycle that determines the amount of rainwater that enters the soil and becomes surface runoff; also, infiltration plays an essential role in the availability of groundwater [1, 2]. The western part of Semarang City is an ideal location to study the effect of land characteristics on the infiltration rate since it often experiences floods [3, 4]. Population growth that continues to rise, followed by changes in land use related to urbanization, influences the produced land characteristics [5]. The geological condition of the western part of Semarang is mainly composed of volcanic rocks in the north and alluvium in the south [6]. Each type of rock and soil has different physical properties related to infiltrating water [7]. Soil with sand-grain-sized composition will have greater infiltration capacity than clay due to the larger void size of the sand [8].

2 Materials and methods

The study area was located in western part of Semarang city, Indonesia as shown in Figure 1. The infiltration rate was measured using a Turf-tec infiltrometer. The measurement was made on the Horizon-A of the weathered soil, then every value generated from the infiltrometer at each measurement point was recorded. At each point, measurement was carried out for 45 minutes. The measurement point was determined by dividing the work area into a grid measuring 2×2 km² with 49 grid points—each grid required at least one infiltration rate measurement data (Figure 2). The turf-tech was plugged into the soil to a depth of 5 to 10 cm. Then the outer and inner cylinders were filled with water to a height of 5 – 20 cm when infiltration occurred, water was added until it reached a quasi-steady flow, or the decrease in water inside the cylinders became constant. To estimate the value of the actual infiltration rate, the infiltration rate was estimated using infiltration model equation. One of the equations of the infiltration model that is often used is the Kostiakov empirical model. The Kostiakov infiltration equation model is an empirical model based on field measurements [7]. The Kostiakov equation was chosen in this research due to its simple form compared to other methods. The Kostiakov equation relates infiltration to time as power function:

$$F_p = at^b \rightarrow y = ax^b \tag{1}$$

where cumulative infiltration (Fp in mm), time after infiltration begins (t in hours), a and b are the parameters obtained through fitting curves that should be evaluated from the measured infiltration data, since those parameters have no physical meaning [9]. Microsoft Excel was used to calculate the infiltration data and making the graphs in this research. Soil properties including grain size, water content, void ratio and degree of saturation was tested based on soil standard test refer to Liu and Evett [10].

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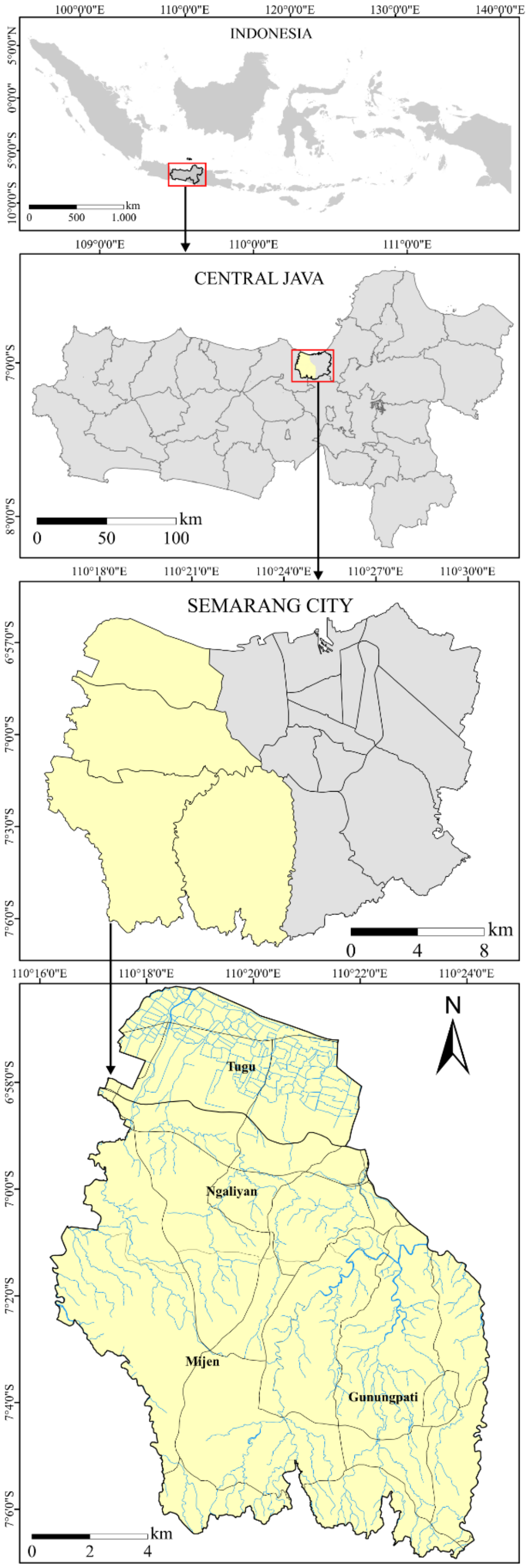

Fig. 1. The study area.

3 Result

3.1. Infiltration rate

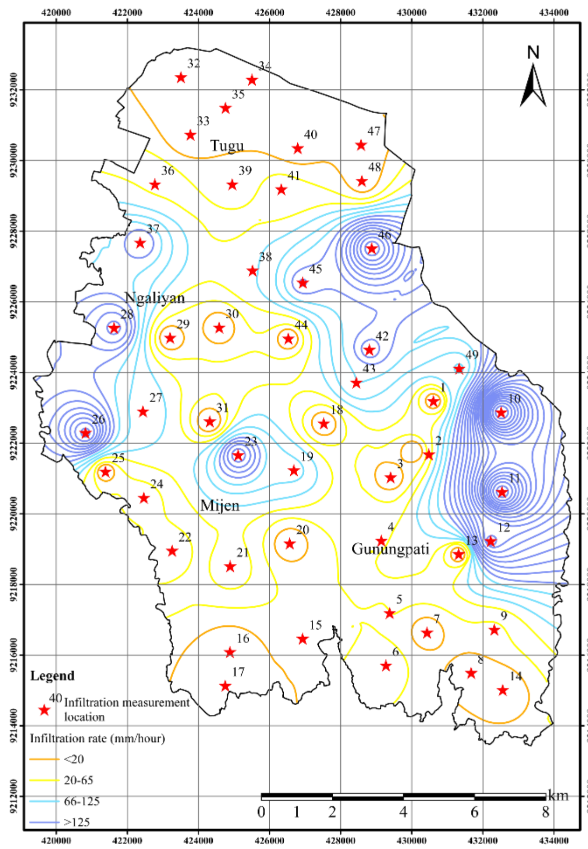

Fig. 2. Infiltration value map and measurement point location.

Figure 2 is a contour map of the infiltration rate in the research area, divided into four classes of infiltration rate contours; the classification of infiltration rate contour classes is based on the simplified classification of Konhke (1968)[11]. The contour of the infiltration rate <20 mm/hour (orange) is included in the classification of Konhke (1968)[11] into the very slow to moderately slow infiltration rate class; the contour of the infiltration rate of 20 to 65 mm/hour (yellow) is included in the medium infiltration rate class; the infiltration rate contour >66 to 125 mm/hour (light blue) belongs to the quite fast infiltration rate class, and the infiltration rate contour >125 mm/hour belongs to the fast to very fast infiltration rate class..

3.2 The influence of soil characteristic

3.2.1. The effect soil texture

Figure 3 show that the exponential regression model had the highest coefficient of determination, namely R^2 = 0.2866, which means that 28.66% of the variation of the infiltration rate variable could be explained by the variable composition of the fine fraction; while the remaining 71.34% was influenced by other variables. It can be seen from the negative trend, indicating that the lower the infiltration rate, the finer the resulting soil type. These results supported the existing theory and previous study, which shows that the higher the fine material in the soil, the infiltration rate will decrease due to the smaller void size [12]. The soil texture parameter had the smallest effect on the infiltration rate, and this is

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because, in the field conditions, other parameters also affected the infiltration rate. When rainwater hit the soil surface, the infiltration was affected by the texture of soil, but all components that made up the soil simultaneously affected the infiltration rate. It can be seen in the graph that some plotting points did not follow the established trend between infiltration rate and soil type (the grey circle in Figure 3), points with coarse-grained soil types produced very slow infiltration rate values due to the water content and the degree of saturation in the high soil. Moreover, the results of plotting the fine-grained soil, which showed several points with grained soil types, actually provided a fast infiltration rate due to the low water content and degree of saturation in the soil and very high water content porosity in the soil.

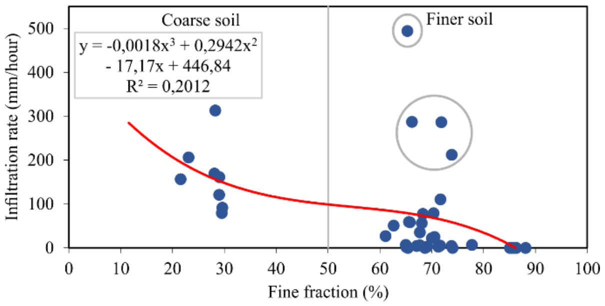

Fig. 3. Correlation between infiltration rate and soil texture.

3.2.2 The effect of soil porosity

Figure 4 show that the polynomial regression model had the highest coefficient of determination, namely R^2 = 0.4854, which means that the porosity variable could explain 48.54% of the variation of the infiltration rate variable in the soil. In comparison, other variables influenced the remaining 51.46%. It can be seen from the positive trend, indicating that the higher the infiltration rate, the greater the porosity in the soil. These results supported the previous study, which show that the value of soil porosity was directly proportional to the value of the infiltration rate [13]. At some points, the plotting results did not follow the trend between the infiltration rate and the porosity in the soil (the grey circle in Figure 4), such as at the points with low soil porosity, which resulted in a high infiltration rate due to the influence the water content and the saturation in the low soil, and located on the coarse-grained soil type, as well as on the results of plotting the porosity in high soils which gave a low infiltration rate due to the high water content and the degree of saturation in the soil, as well as being in the fine-grained soil.

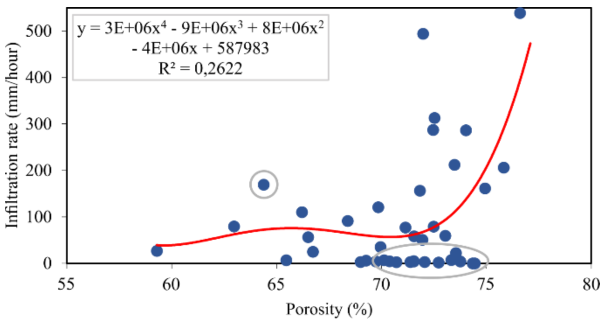

Fig. 4. Correlation between infiltration rate and soil porosity.

3.2.3 The effect of soil water content

Figure 5 show that the exponential regression model had the highest coefficient of determination, namely R^2 = 0.4560, which means that 45.60% of the variation of the infiltration rate variable could be explained by the variable water content in the soil. In comparison, the remaining 54.40 % was influenced by other variables. It can be seen from the negative trend, indicating that the lower the infiltration rate, the greater the water content in the soil. This relationship confirmed by another study show that the higher the water content in the soil, the lower the infiltration rate [14]. At some points, the plotting results did not follow the trend between the infiltration rate and the water content in the soil (the grey circle in Figure 5), such as at the points with low water content in the soil, which resulted in a low infiltration rate due to the influence of porosity in the low soil, as well as the results of plotting the high water content in the soil which gave high infiltration rate due to the very high porosity in the soil.

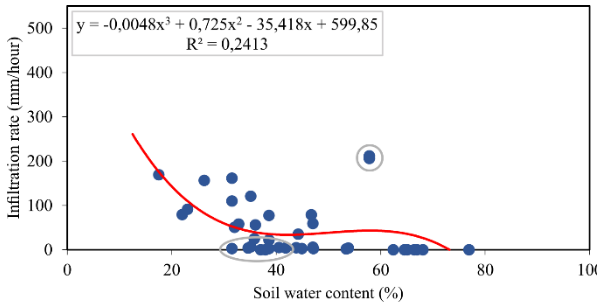

Fig. 5. Correlation between infiltration rate and soil water content.

3.2.4 The effect of soil void ratio

Figure 6 show that the polynomial regression model has the highest coefficient of determination, namely R^2 = 0.3438, which means that 34.38% of the variation of the infiltration rate variable can be explained by the void ratio variable in the soil, while the remaining 65.62 % influenced by other variables. It can be seen from the positive trend indicating that the higher the infiltration rate, the greater the void ratio in the soil. These results supported the previous research, which explains that the value of the soil is directly proportional to the value of the infiltration rate [14]. At some points, the plotting results do not follow the trend between the infiltration rate and the void ratio in the soil (grey circle in Figure 6), as at points with a low void ratio in the soil, and it results in a high infiltration rate due to the influence of water content and saturation in low soils, and being in coarse-grained soil types, as well as the results of plotting a high void ratio in the soil gives a low infiltration rate due to the high water content and degree of saturation in the soil, as well as being in fine-grained soils.

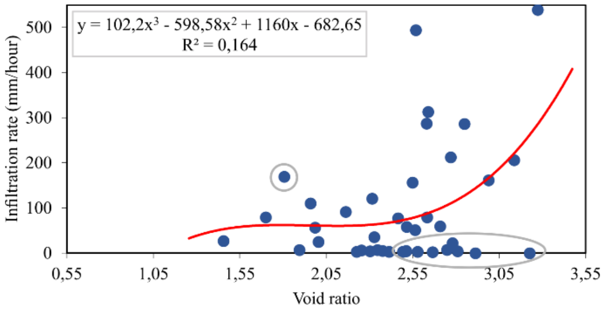

Fig. 6. Correlation between infiltration rate and void ratio.

3.2.5 The effect of degree of saturation

Figure 7 show that the exponential regression model had the highest coefficient of determination, namely R^2 = 0.3956, which means that 39.56% of the variation of the infiltration rate variable could be explained by the degree of saturation in the soil, while other variables influenced the remaining 60.44%. It can be seen from the negative trend, indicating that the lower the infiltration rate, the greater the degree of saturation in the soil. This supported the previous finding that the more saturated the initial conditions of soil, the lower the infiltration rate [15]. At some points, the plotting results did not follow the trend between the infiltration rate and the degree of saturation in the soil (the grey circle in Figure 7), as at the points with a low degree of saturation in the soil, which resulted in low infiltration rate due to the influence of porosity in the low soil, as well as the results of plotting the degree of saturation in the high soil which gave high infiltration rate due to the very high porosity in the soil.

4 Discussion

The test of the simple regression model above aimed to examine the extent of effects of each parameter from the five parameters which had been determined in this research on the infiltration rate. The reality was that there were still many other parameters remain that affected the infiltration rate, such as soil density, organic element content, temperature, structure, land slope, land use, and others [16-19].

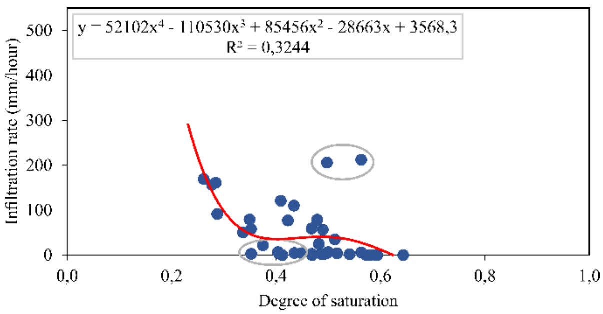

Fig. 7. Correlation between infiltration rate and degree of saturation.

The coefficient of determination (R^2) is an index to determine how much variability in the dependent variable can be explained by the regression model. In The result of all parameter investigated in this study show that the R^2 value has a relatively low value (<0.50), with the lowest R^2 value in the soil texture parameter, which was 0.2923. In previous research conducted by Fauzan and Har [20] regarding soil physical properties, slope, and lithology on the value of the infiltration rate in Padang City, also gave low R^2 results. Low correlation results were also produced in research by Fitzgerald et al. [21] and concluded that there might have been other parameters with better correlation, either the infiltration measurement method using the infiltrometer was not reliable, caused by plugging the infiltrometer into the soil, which disturbed the physical properties of the soil, therefore the soil inside the ring did not represent the type of soil around it. Another factor is due to the effect of size scale of the used ring infiltrometer, in which according to Li et al. [22], the double-ring infiltrometer is having a size-scale impact where the larger the ring size in the used infiltrometer, the scale effect decreases, and the scale effect does not occur when using a 40-cm diameter inner ring.

5 Conclusion

The results of the infiltration rate measurement show that, in the western part of Semarang City, the infiltration rate varies from very slow to very fast, with the infiltration rate of 0 to 1601.33 mm/hour. The values of the very slow to moderate infiltration rate class are spread in the Tugu District and partly in the Mijen District. In contrast, the values of the fast to very fast infiltration rate class are distributed in the Ngaliyan District and partly in the Gunungpati District. Meanwhile, the correlation results graphically show that the soil type, water content, degree of saturation, and porosity correlate to the infiltration rate in the western part of Semarang City. The parameter of soil texture has the smallest relationship to the infiltration rate with an R^2 value of 0.2923, and the porosity in the soil has the largest relationship to the infiltration rate in the research area with an R^2 value of 0.4854.

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