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Relation of Soil Physical Parameters and Dominant Vegetation with Infiltration Capacity in Latuppa Sub-Watershed Palopo Indonesia

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Abstract. *The infiltration capacity is the soil's ability to accommodate water that seeps into the soil, reducing surface runoff that will cause flooding, such as in the downstream area of Palopo City. This study aimed to determine the influence of dominant vegetation and soil physical characteristics on infiltration in the upstream area of the Latuppa Sub-Das, Mungkajang District, Palopo City. Data collection was carried out by direct observation in the field in a purposive manner in 10 plots, which represent the condition of vegetation in the upstream area of the Latuppa watershed, and each plot consisted of 3 replications to observe infiltration and soil samples. The data were analyzed using the rational method, the Horton method, and vegetation index analysis. Additionally, the data were analyzed via simple linear regression and multiple regression analysis to determine the influence of the dominant vegetation and physical characteristics of the soil on the infiltration capacity. The highest infiltration capacity was found in plot 10, with an infiltration capacity of 107.5 mm/minute (6,450 mm/hour) and an average infiltration rate of 0.4 mm/minute (24 mm/hour). The dominant vegetation cover is Cananga odorata, with a vegetation index value of 78.41%. Plot 10 has a height of 362.79 masl, a gentle slope, a crumbly soil structure, a clay sand texture, a very high soil density, and 2.10% organic matter. Based on observations and data analysis, the factors that influence the infiltration capacity in the upstream area of the Latuppa subwatershed are vegetation conditions, altitude, slope, and physical properties of the soil.*

Keywords: *infiltration capacity, soil physical characteristics, vegetation dominant*

Citation

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INTRODUCTION

The Latuppa watershed has an area of 6,843.02 ha, and the length of the river reaches 59,472 meters, which has considerable potential for water resources as a raw water source for the Municipal Water Company (PDAM) of Palopo City and irrigation of agricultural land. Currently, the watershed is facing severe problems. Settlements are widespread due to extreme topographic conditions and land use patterns, and conservation regulations are still not considered (Yumna et al., 2019). As a result, in the last decade, there have been various cases, such as floods and landslides in the rainy season and drought in the dry season (Avia, 2019; Hapsari & Zenurianto, 2016; Manandhar et al., 2015).

The increasingly critical river hydrology causes the ratio between the maximum discharge in the rainy season and the minimum discharge in the dry season to improve (Guo et al., 2018; Phi Hoang et al., 2016), and land productivity will decrease, especially in the upstream parts of the watershed (Sukisno et al., 2023), which will result in flooding in the rainy season and drought in the dry season. Land use change is one of the most significant contributing factors to flooding (Sukisno et al., 2023; Molla et al., 2022).

Infiltration, as a factor in the hydrological cycle, is vital in the distribution of rain. It dramatically influences surface runoff, flooding, erosion, plant water availability, underground water, and irrigation water during the dry season. Soil and vegetation properties generally influence infiltration. Different types of land use affect the role of vegetation in infiltration. According to Shao & Baumgartl (2014), the infiltration parameter is controlled by soil factors, vegetation, and rainfall. The infiltration capacity is the ability of the soil to seep a large amount of water into the soil. A high infiltration capacity can reduce ongoing surface runoff. In general, soil compaction can reduce the number of soil pores, which will cause low infiltration (Shah et al., 2017; Bojko & Kabala, 2016; Suripin & Kurniani, 2016).

Vegetation cover on the soil surface can increase the infiltration rate of land. Vegetation is a vital factor in determining infiltration capacity. Soil tends to be more prevalent than nonvegetated soil (Zhao et al., 2021). Vegetation at the tree level can increase infiltration capacity and store water(Zhao et al., 2021; Yu et al., 2018; Suharto, 2006). This research aimed to determine the influence of dominant vegetation and soil physical characteristics on infiltration capacity in the upstream Latuppa subwatershed, Mungkajang District, Palopo City.

MATERIALS AND METHODS

Research Location

Measurements of vegetation data, infiltration capacity, and soil physical characteristics were performed in the Latuppa subwatershed, Mungkajang subdistrict, Palopo city, as shown in Figure 1. Geographically, the Latuppa watershed is located at latitudes 2°59'9.9"-3°4'2.5"S and longitudes 120°5'2.3"-120°13'52.88"E with an area of 6,843.02 ha. The area of the Latuppa watershed, which is based on two administrative regions, is 94.33% or equal to 6,455.14 ha in the city of Palopo and 5.67% or similar to the 387.88 ha area in the Luwu district

Data collection

The The research data consisted of primary data and secondary data. The initial infiltration rate (f0), final infiltration rate (fc), and constants for soil types and surfaces (k) were used to measure the infiltration capacity of sub-DAS Latuppa. These data were obtained according to plot placement and measured using a double-ring infiltrometer. In addition, vegetation data consisting of the amount and type of vegetation, height, and diameter of vegetation stems were used to measure the IVI index, and soil samples were

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were collected using a sample ring to analyze the physical characteristics, soil density, and organic matter.

Data collection and plot placement were performed by purposive sampling following the river border on both sides. Five plots are on the left edge, and five are on the right edge. The aim of making plots was to analyze vegetation data for an area of 20 meters × 20 meters for each plot using the census method for tree categories. Additionally, three repetitions of soil samples were used for each plot to measure the infiltration capacity. The secondary data were obtained through a literature review of journals and books.

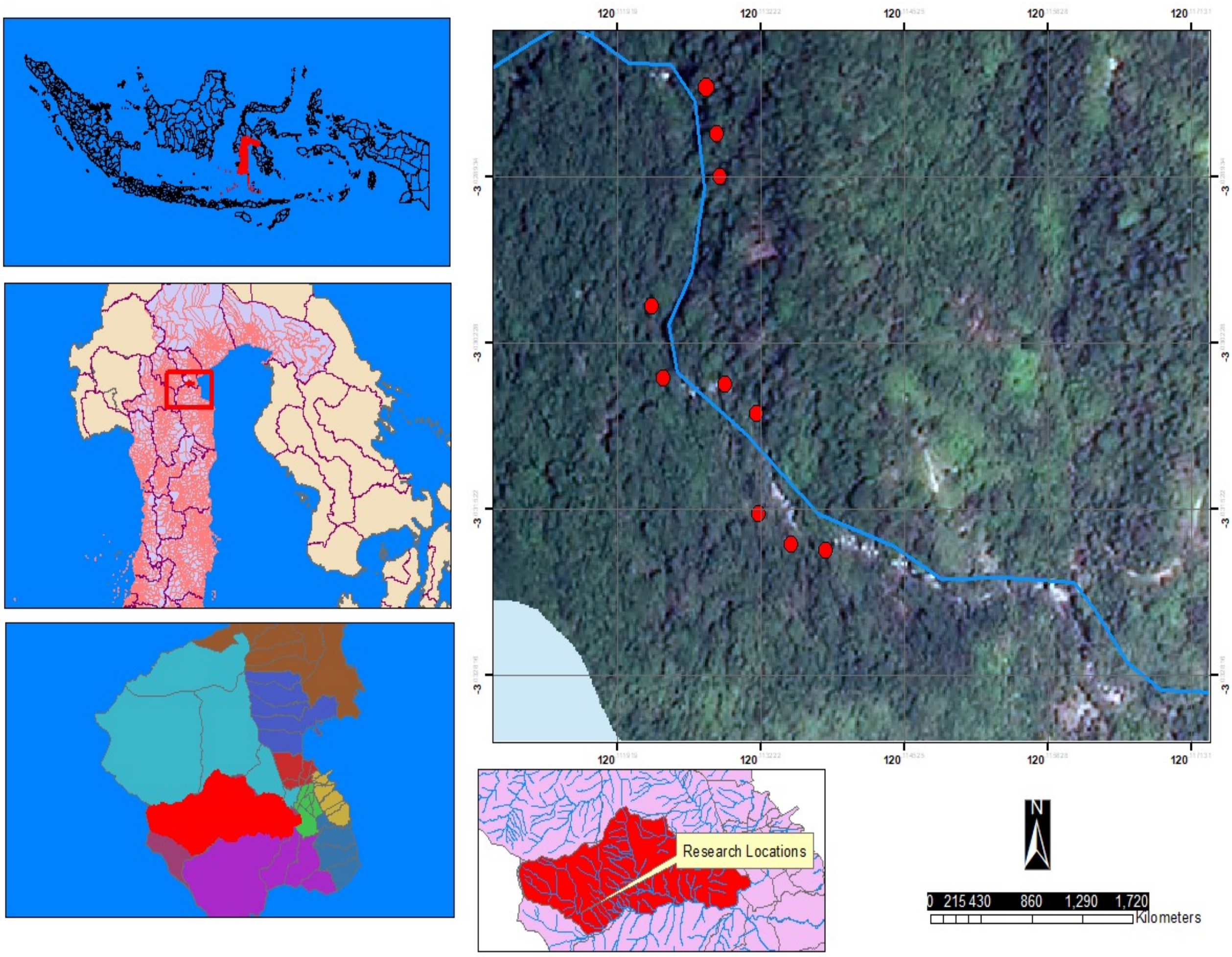

Figure 1. The map of the research area

The results of the initial observations in the study obtained data on the height and slope at the research location, which are presented in Table 1. It can be concluded that each plot has a different height and slope that can affect the infiltration rate in each plot. According to Yang & Huang (2023) and Vahedifard et al. (2016), the lower the slope is, the greater the infiltration.

Data Analysis

Vegetation analysis

Vegetation composition is measured by the important value index (IVI), which is a combination of relative density (RD) and relative frequency (RF). This was followed by the IVI, RD, and RF calculations of Indriyanto (2010), as described below:

Tree diameter (Dm)

Dm= circum/π

Density (D)

$$\text{Density (D)} = \frac{\sum \textit{The number of individuals throughout the sample plots}}{\text{sample area}}$$

Relative density

$$(\text{Relative density}) = \frac{D\ a\ species}{D\ all\ species} \times 100\%$$

Frequency (F)

$$\text{Frequency (F)} = \frac{\textit{Number of discovery tiles of a type}}{\text{Number of all sample plots}}$$

$$\text{Relative Frequency (FR)} = \frac{\text{F s species}}{\text{F all species}} \times 100\%$$

Dominance

$$\text{Relative dominance} = \frac{\textit{Dominace a species}}{\textit{Dominance all species}} \times 100\%$$

$$\text{Dominance} = \frac{\textit{Base area of a species}}{\textit{Sample plot size}}$$

Importance Value Index (IVI)

IVI = RD + RF + RD

Analysis of soil physical characteristics and organic matter

The physical characteristics of the soil in terms of structure and texture were obtained by referring to the Soil Science Guidebook (Hardjowigeno, 2007). Measurements of soil density and organic matter were obtained from analyses of soil samples at the Soil Chemistry and Fertility Laboratory at Hasanuddin University. Soil sample analysis was carried out to determine several physical properties of the soil using the analysis methods listed in Table 1. Data analysis was carried out using a descriptive method, namely, explaining a situation in the field based on the soil characteristics.

Table 1. Variables Observing Soil Physical Properties and Methods of Analysis

Observed Variables	Analysis Method
Bulk density	Gravimetric
Texture	Pipette
Saturated water level	Gravimetric
Water content field capacity	Gravimetric
C-Organic	Walkley and black say

Analysis of infiltration capacity

According to Susanawati et al. (2018), measurements in the field obtained data in the amount of water decreased in each treatment for later processing. Data on the infiltration rate at each time (f_t) and constant infiltration (f_c) are obtained from processing these data. The field infiltration can be formulated in Equation 1.

$$f_t = (\text{Depth})/(\text{T})$$

In above formula, f_t is the infiltration rate, Depth is the cumulative water input (entering the ring infiltrometer's soil (mm)), and T is the time interval for observing water entering the ring infiltrometer (minutes).

The data were processed using the Horton infiltration model. The Horton method can be formulated in Equation 2.

$$F_t = f_c + (f_0 - f_c)\ e\text{-}kt$$

In above formula, F_t is the infiltration rate, F_c is constant infiltration rate, F_0 is the infiltration rate at the time of measurement, K is the infiltration rate decreasing constant, e is the Euler's number (2.718 or 2.72), t is cumulative time from the beginning of the rain, and kt is the constant depending on soil conditions and vegetation cover

Based on the main formula, several parameters are determined using the Horton method, namely:

(a). K value

The constant K is obtained by using the general linear equation

$y = mx + c$

$y = tx = \log (f - f_c)$

$m = (-1)/({}^{k}\log e)$

$c = (-1)/({}^{k}\log e) \log (f_0 - f_c)$

We use the following equation:

$m = (-1)/({}^{k}\log e)$

$k = (-1)/({}^{m}\log e)$ or $k = (-1)/0{,}4343xm$

In above formula,M is the gradient obtained from plotting the relationship between the actual field/infiltration (f) (mm.hour-1) and log (f_c) (mm.hour-1) (using Ms. Excel 2010) so that the value obtained is obtained by the regression equation linear (y=mx+c).

(b). The value of f_c is obtained from the infiltration value when it reaches a steady state.

(c). The f_0 value is obtained from the infiltration value when it is in the initial state.

Analysis of statistics

The statistical approach used was simple linear and multiple linear regression. The model equation is as follows:

$$Y=a+bX$$

$$Y=a+b_1X_1+b_2X_2+...., b_iX_i$$

This equation was used to determine the significant influence of bulk density (X_1), organic matter (X_2), dominant vegetation (X_3), and infiltration capacity (Y).

RESULTS AND DISCUSSION

Importance Value Index of Vegetation

The importance value index obtained in each plot has a huge difference. There were *Dracontomelon* sp., *Cananga ordorata*, *Durio Zibethinus*, *Vitex cofassus*, *Magnoliaceae*, *Litsea mappacea* Boerl. Figure 2 shows that plot 8 had the highest IVI at the tree level (153.30%), and the dominant vegetation type was *Litsea mappacea* Boerl. *Litsea mappacea* trees are sub-canopy trees up to 22 m tall and 47 cm in height. Stipules absent. Leaves alternate, simple, penni-veined, hairy below, base sometimes cordate. Flowers ca. 10 mm in diameter, white-yellow, placed in panicles. Fruits ca. 14 mm long, red-purple, drupes. The ecology of this species is undisturbed to slightly disturbed mixed dipterocarp to swamp forests up to 1000 m altitude. They are usually located on alluvial sites and along rivers and hillsides. On sandy to clay soils. In secondary forests, a pre-disturbance remnant tree usually occurs (Kusparadini et al., 2018).

The lowest Important Value Index is in Plot 1 at the tree level of 45.19%. The predominant type of vegetation is the *Dracontomelon* sp. The *Dracontomelon dao* plant belongs to the Anacardiaceae family, which is spread throughout Indonesia and is widely used as a traditional medicine. Dracontomelon dao grows across lowland forests. This type can grow in good to extreme soil conditions, especially in alluvial soil and swamp areas (Putri et al., 2022). According to Ali et al. (2022), the IVI is influenced by the large stem diameter and many vegetation types. According to (Seiwa et al., 2021; Fischer et al., 2015; Endarwati et al., 2017), a higher density, diversity, richness, and uniformity of a vegetation index can increase the infiltration rate well. IVI values in different observation plots are affected by the kind of vegetation and the average size of the trunk diameter of each tree of the same species (Isa et al., 2023; Ganamé et al., 2019; Gunawan et al., 2012).

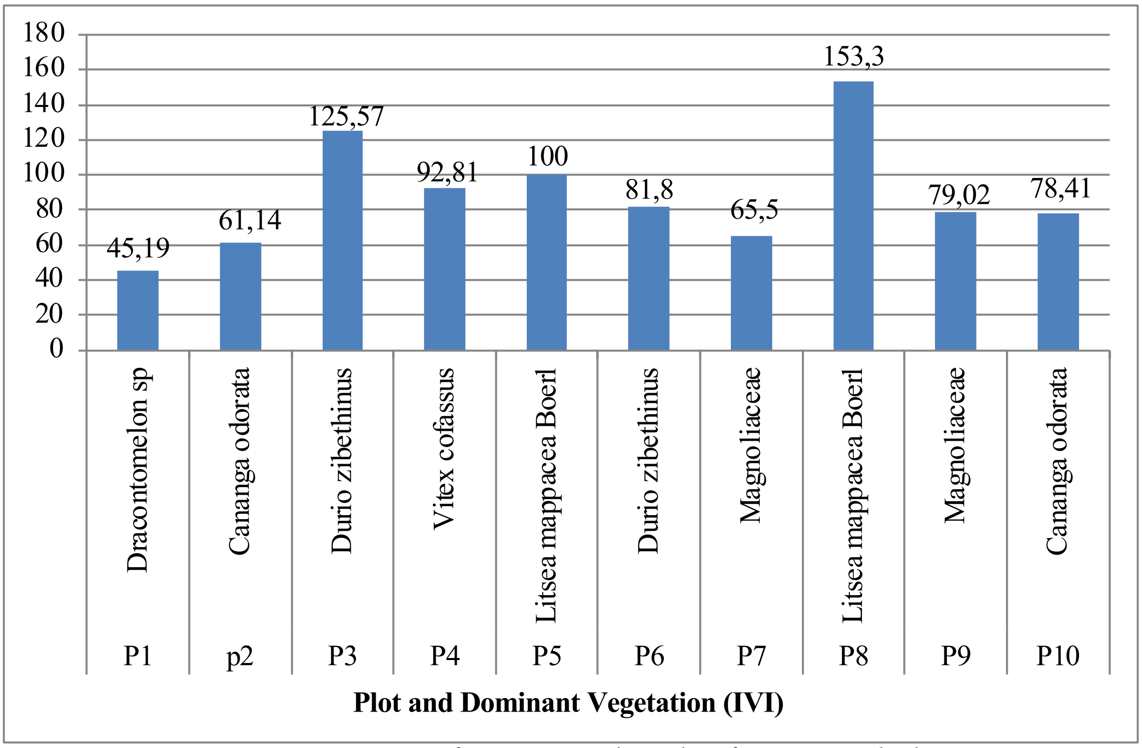

Figure 2. Comparison of Vegetation Index Values for 10 Research Plots

Soil physical characteristics and organic matter

Soil structure is a soil physical property that describes the spatial arrangement of soil particles that combine to form small lumps. These small lumps come in different shapes, sizes, and levels of resilience. Moreover, soil texture is the relative comparison of various main classes of soil particles in a soil mass, especially clay, loam, and sand fractions (Xia et al., 2020; Jaconi et al., 2019). The results of the soil's physical and chemical property measurements are shown in Table 2.

Soil sampling in 10 observation plots aimed to obtain data on the physical characteristics of the soil. The results of the data analysis show that there are two types of soil structures in all the observation plots, namely, granular and crumb structures. Crumbly soils have more macro pores, so water flows into the soil more quickly (Beven, 2018), while granular soils with fewer macro pores will be hampered (Lin et al., 2020; Jim & Ng, 2018). Soil texture analysis in the observation plot revealed two types of soil textures: loamy and clay sand. Soil with a significant enough percentage of sand will easily allow water to pass into the soil and vice versa (Sharma

& Malaviya, 2021; Haghnazari et al., 2015) analysis of soil density data (bulk density) at all observation plots revealed different soil density levels. The soil with the highest density was in plot 9, with a value of 1.26 (grams/cm³), while the lowest density was in plot 8, with a value of 1.00 (grams/cm³).

The characteristics of soil show that the denser the soil is, the greater the weight of its contents, which means that it will be more difficult for water to enter into the soil (infiltration and percolation) (Jarvis, 2007;Lin et al., 2020;Jim & Ng, 2018) or be penetrated by plant roots (Asdak, 2004). Dense soils have fewer macro pores than crumbly soils Isa et al., (2023), so water will be obstructed (Widianto et al., 2004). The soil organic matter content differed among the observed plots. The soil with the highest organic matter content was found in plot 7, with a value of 2.31%, while the lowest was found in plot 3, with a value of 1.67%. The higher organic matter in the soil is more significant than the pore space in the soil (Zsolnay, 2003;Holilullah et al., 2015).

According to (Hairiah et al., 2006;Hairiah et al., 2004), soil organic matter affects the physical properties of the soil, including increasing the ability to hold water. The color of the soil changes from brown to black, which stimulates the granular aggregates of the soil, stabilizes it, and reduces plasticity, cohesion, and other harmful properties from the influence of clay (Saputra et al., (2022).

Table 2. Soil physical and chemical characteristics

Plot	Physical characteristics of Soil				
	Soil Structure	Soil Texture	Bulk Density (grams/cm³)	Criteria	Organic matter (%)
p1	granular	Clay Sand	1.13	Very high	2.03
p2	granular	Clay Sand	1.23	Very high	1.81
p3	granular	Clay Sand	1.02	Medium	1.67
p4	Crumb	Loamy sand	1.01	Medium	1.85
p5	Crumb	Loamy sand	1.17	Very high	2.13
p6	granular	Loamy sand	1.04	High	1.99
p7	granular	Loamy sand	1.01	Medium	2.31
p8	Crumb	Loamy sand	1.00	Medium	2.02
p9	granular	Loamy sand	1.26	Very high	2.20
p10	Crumb	Loamy sand	1.34	Very high	2.10

Infiltration rate

The plots with the highest infiltration rates were plot 8 (0.15 cm/min or 1.5 mm/min) or 90 mm/hour (see Figure 3). Some factors influencing vegetation cover are dominated by Sinangkala (Litsea mappacea) plants, with an IVI value of 153.30%. Vegetation has a significant influence on the process of soil infiltration because plant roots, apart from helping to absorb water that enters the soil (Liu et al., 2019), due to increased evapotranspiration, also help form water channels into the soil in the form of rotting roots (Huang et al., 2013).

Other influencing factors are the height and slope of plot 8, which is 383.95 meters above sea level with a pitch of 70 (19.44%), which is rather steep. The steeper the slope of the land is, the longer time is required to reach the infiltration capacity. Similarly, Zsolnay (2003), Isa et al. (2023), and Qur'ani et al. (2022) state that the lower the slope is, the greater the infiltration. The soil structure and

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texture in plot 8 are crumbly, while the soil texture is loamy sand. According to (Huang et al., 2013 and Vahedifard et al., 2016), the more crumbly and larger the soil pores are, the greater the infiltration rate. According to Dong and Ochsner (2018), the higher the clay content or the finer the soil fraction is, the higher the groundwater content.

On the other hand, the higher the coarse fraction (very coarse sand or medium coarse sand) is, the lower the soil water content. The soil density in plot 8, with a value of 1.00 (gram/cm³), is categorized as medium, indicating that the density is inversely proportional to infiltration. The lower the density is, the greater the infiltration rate (Hardjowigeno, 2007). Moreover, the soil organic matter content in plot 8 was 2.02%, indicating that soil organic matter can increase structural stability and soil porosity to accelerate water entry into the soil.

The lowest infiltration rates were found in plots 3 and 10, with values of 0.04 cm/minute or 0.4 mm/minute (24 mm/hour), respectively. Several influencing factors included vegetation cover in plot 3 of Durian (Durio zibethinus) with an IVI value of 125.57% and Cananga odorata with an IVI value of 78.41%. In addition, the height factor in Plot 3 is 436 m above sea level, and a slope of 85° (23.61%) is classified as Slightly Steep. Moreover, plot 10 is 362.79 m above sea level, and a slope of 50° (13.89%) is categorized as sloping. According to (Qur'ani et al., 2022), the lower the slope is, the greater the infiltration value obtained. The soil structure in plot 3 is granular and has a loamy sand texture, while in plot 10, the soil structure is crumbly with an earthy sand texture. According to Liu et al. (2019), the larger the soil pores are and the more crumbly the soil is, the greater the infiltration rate. The texture of sandy loam had a lower infiltration rate than the sandy loam. The infiltration shows that the coarser the soil texture is, the faster water will enter the soil, and vice versa; the finer the soil texture is, the slower water will enter the ground (Nurmegawati et al., 2012). The soil density in plot 3 was 1.02 (gram/cm³), which was categorized as medium. Plot 10 shows a value of 1.34 (gram/cm³) in the very high category. Soil density indicates that the denser the soil is, the greater the weight of its contents, which means that it is more difficult for water to continue (infiltration and percolation) or to be penetrated by plant roots (Asdak, 2004). The organic matter in plot 3 is 1.67%, and that in plot 10 is 2.10%. Organic matter means that soil organic matter increases structural stability and soil porosity, ultimately accelerating the inflow of water into the soil (Lefroy, 2002).

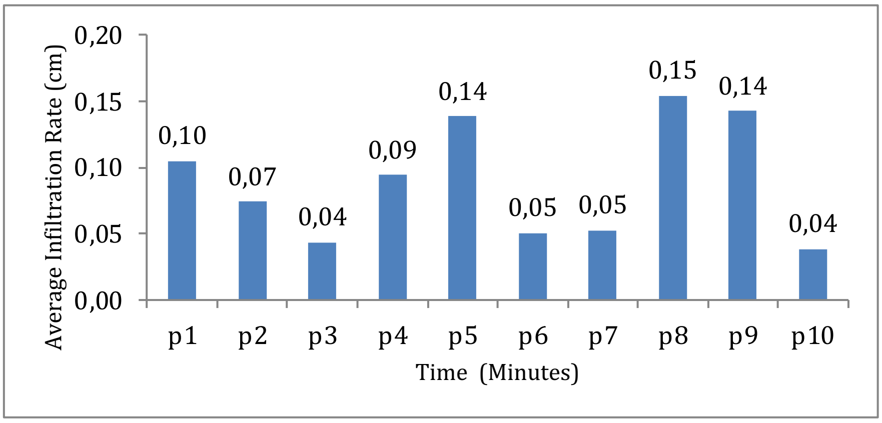

Figure 3. Average infiltration rate

Infiltration capacity

The highest infiltration capacity was found in plot 10, namely, 10.75 cm/minute or 107.5 mm/minute (6,450 mm/hour). The height of plot 10 is 362.79 masl, with a slope of 50° (13.89%), which is categorized as sloping. According to Jim and Ng (2018), the lower the pitch is, the greater the infiltration value. The low infiltration rate and infiltration capacity on a slope of 25-40% are affected by gravity, which causes water to flow vertically into the soil through the soil profile (Chiou et al., 1990).

Plot 10 has a loose soil structure with a clay sand texture. Various types of soil physical properties can influence the infiltration capacity of a location. Soil structure is the controller of soil hydrology. Soil structure is influenced by the level of addition of organic material or the level of soil processing in various land uses (Sukisno et al., 2023; Yumna et al., 2019). The soil density in plot 10 was 1.34 (grams/cm³), which was very high. This shows that the denser the soil is, the greater the weight of its contents, which means that it is more difficult for water to pass through (infiltration and percolation) or be penetrated by plant roots (Asdak, 2004). Reduced soil pores, generally caused by soil compaction, lead to reduced infiltration (Saputra et al., 2022).

The organic material in plot 10 is 2.10%, meaning that soil organic matter increases the soil structure and porosity stability and ultimately accelerates water entry into the soil. A high organic matter content affects the pore space. The greater the organic material content in the soil, the greater the pore space in the soil (Peth et al., 2014). The lowest infiltration capacity was found in plot 9, namely, 5.77 cm/minute or 57.7 mm/minute (3,460 mm/hour), with an average infiltration rate of 0.14 cm/minute or 1.4 mm/minute (84 mm/O'clock), respectively. These data are obtained based on the time of infiltration measurements in the morning. The low infiltration capacity can be influenced by several factors, including the vegetation cover in plot 9, namely the Uru (Magnoliaceae) plant, which has a reasonably low IVI value compared to the other plots, namely 79.02%.

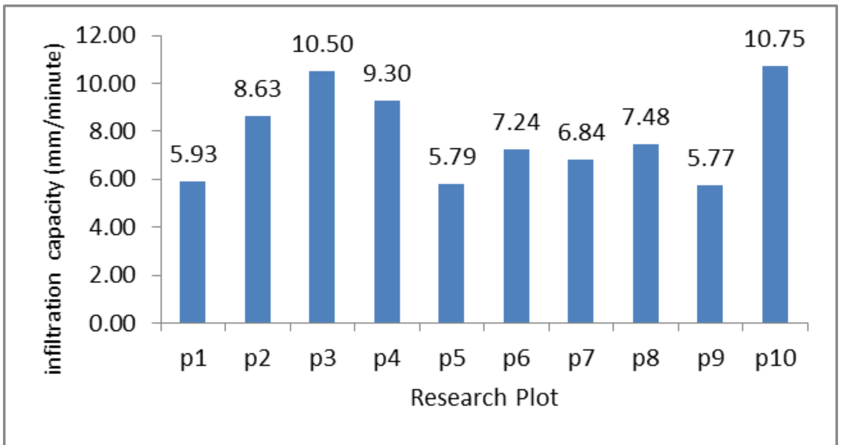

Figure 4. Average infiltration capacity

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Another influencing factor was the altitude (363.36 masl), with a slope of 70° (19.44%) categorized as rather steep. Furthermore, the soil structure in plot 9, which has a granular texture and loamy sand texture, can affect the infiltration capacity of a place. The soil density in plot 9 is 1.26 (grams/cm³) Very High, meaning that in plot 9, it is difficult for water to pass through (infiltration and percolation) or penetrate by plant roots because the denser the soil is, the greater its weight (Asdak, 2004). Similarly, the organic matter in plot 9 was 2.20%. According to (Hairiah et al., 2004), organic matter in soil influences the physical properties of the soil, including increasing the ability to hold water, turning the color of the soil from brown to black, stimulating the granularity of soil aggregates, and solidifying them, and reducing plasticity, cohesion, and other harmful properties from the influence of clay.

Regression analysis

Simultaneous regression analysis revealed that infiltration capacity was influenced by dominant vegetation and soil characteristics and was even very small. There are three variables: bulk density (X1), organic matter (X2), dominant vegetation (X3), and infiltration capacity (Y).

The regression equation was Y=14,628+4,068X1-6,133X2+0,010X3. This equation shows that all variables have a non-significant influence on infiltration capacity. The P value was greater than 0.05%, with a multiple regression value of 0.66 (66%), which included the strong category. This means that all the measured variables do not simultaneously influence the infiltration capacity.

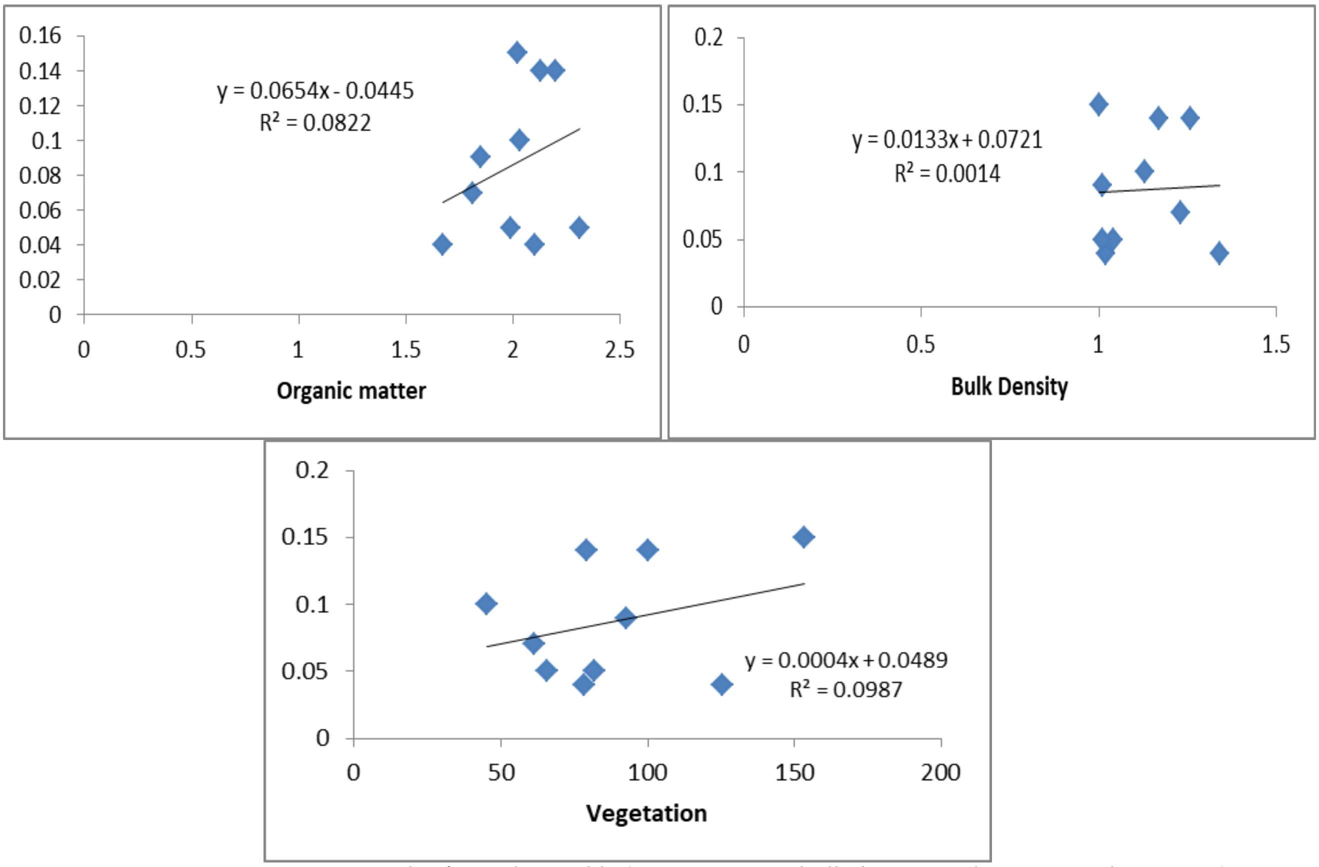

Figure 5. Regression scatter plot for each variable (organic matter, bulk density, and vegetation dominance)

Figure 5 shows that the low correlation between variable X and Y is caused by several factors, including the following: the level of data variation for all variables in each observation plot is shallow or tends to be homogeneous. This is also shown by the land conditions, which tend to be the same as those in the slope data (Table 2). The soil structure is also the same, as is the homogeneous texture.

A thorough analysis of all observation variables shows that infiltration capacity is influenced by several variables, such as vegetation and the physical characteristics of the soil, although they are not significant. These results indicate that activities in the Latuppa subwatershed with specific locations in the Mungkajang subdistrict did not significantly influence the conditions of the Latuppa watershed.

CONCLUSION

Based on regression analysis, all measured variables do not simultaneously influence infiltration capacity. This is caused by several factors, including the low level of data variation for all variables in each observation plot or the fact that it tends to be homogenous. The infiltration capacity in the entire plot ranged from 5.77-10.75 mm/minute (57.5-107.5 mm/hour), with an important index ranging from 45.19-153.30%. The vegetation types that dominate the research plot are Litsea mappaceae, Durio ziberthinus, Dracontomelon sp., Cananga odorata, Vitex cofassus and Magnoliaceae. At 362.79 masl, the area has a gentle slope with a crumbly soil structure, loamy sand texture, very high soil density, and 2.10% organic matter.

AUTHOR CONTRIBUTION

Witno and Yumna collected and analyzed the data and wrote the scripts. Abdul Rahim helped design and prepare the raw materials and oversees all the research processes.

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CONFLICT OF INTEREST

The authors declare that in writing this article there is no conflict of interest.

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