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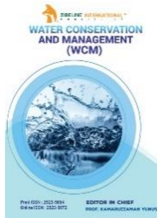

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RESEARCH ARTICLE

SOIL INFILTRATION IN VARIOUS AREAS AS A BASIS FOR HYDRLOGICAL ALTERATIONS IN THE TOBOLI WATERSHED, CENTRAL SULAWESI, INDONESIA

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ABSTRACT

The heterogeneity of infiltration has a strategic influence on the hydrological process in the watershed, and one of the factors affecting its rate and soil compaction is land use. Therefore, this study aims to compare infiltration rates in three land-use areas, namely secondary forest, agroforestry, and moor. A survey method was used, where field data observations were carried out at three locations. The infiltration rate measurement was performed using a double-ring infiltrometer with five repetitions at each sampling site. The results showed that the lowest value of 4.72 cm h^{-1} was recorded on the moorland, while agroforestry had the highest of 12.87 cm h^{-1}. These findings indicate that land use has a significant role in changing soil physical properties and compaction, hence, sustainable soil and water conservation strategies are needed.

KEYWORDS

Land use, soil infiltration, watershed management. Secondary forest, agroforestry, moor.

1. INTRODUCTION

Land conversion in several watersheds has become a serious problem, because it causes a disturbance in the hydrological cycle, such as land damage and infiltration rate reduction due to soil compaction (Wang et al., 2018; Peña-Arancibia et al., 2019; Purba et al., 2020; E. Al-Esawi et al., 2021). Watershed is a basic concept in hydrology, and one of its integral parts is the rate of water inflow into the soil. Furthermore, it is the basis for understanding hydrological processes while planning and managing water resources. An understanding of these processes and groundwater quality is very important to maintain watershed health, through rainwater management, infiltration processes, surface runoff, as well as groundwater and soil erosion (Bhardwaj, 2019; Flotemersch et al., 2016; Aryafar, 2017).

Infiltration is one of the main components of the hydrological cycle, as well as an important variable for predicting various soil processes (Yimer et al., 2008; Tesemma et al., 2015; Devia et al., 2015; Chyba et al., 2017; Khalid et al., 2017). In watershed management, flood and erosion predictions depend on runoffs, which is directly affected by the rate of water inflow (Yan et al., 2015; Naharuddin et al., 2021).

Furthermore, infiltration has a strategic role in watershed ecosystem because it determines the amount of runoff and rainfall that can penetrate the soil. Furthermore, increasing its value helps to infiltrate rainwater into the soil, and this serves as groundwater reserves during the dry season (Fauzan and Rusli, 2018). Infiltration quantification is also needed to determine water availability for plant growth, development, irrigation, and other domestic household purposes (Al-Ismaili et al., 2017; Fischer et al., 2015; Basche and DeLonge, 2019).

Land use that does not follow soil and water conservation principles, such as soil compaction can affect infiltration rate (Návar and Synnott, 2000). The grazing of livestock in pastures has the potential effect of reducing the inflow of water due to disturbances in soil and plant cover. Pressure on forests as well as non-regulation of conservation efforts can remove shrubs, herbs, trees, and grasses, as well as reduce above-ground organic matter, which are parameters for infiltration and minimizing surface runoff.

Land-use change and rainfall are often considered the main factor affecting soil infiltration (Sun et al., 2018; Aliramayee et al., 2019). However, the difference in the capacity for several types of land use is not widely known, especially in secondary forests, agroforestry, and moor. Forest conversion is often accompanied by changes in soil structure due to the use of tillage systems that do not follow conservation principles. This causes compaction of the soil surface, thereby leading to a decrease in the infiltration capacity and water content (Owuor et al., 2018).

Infiltration is a very important hydrological parameter, and it marks the transition of fast-moving surface water to slow-moving groundwater. Several studies have also explored its rate in various land use areas, such as the impact of land use on increasing soil infiltration capacity using meta-analysis , infiltration capacity model, the effect of soil moisture and plant roots on soil infiltration capacity, assessment of infiltration capacity based on the spatial distribution for evaluation of storm runoff in forest catchments, and variation of soil infiltration capacity after vegetation restoration (Tang et al., 2019; Sun et al., 2018; Hamman et al., 2018; Liu et al., 2019; Liu et al., 2020; Miyata et al., 2019). However, none of these studies have compared the rates in various land use areas.

In the tropical area, especially Central Sulawesi, there are dynamic changes in land use from primary to secondary forest land, agroforestry, and other forms. There are also no studies on the infiltration rate in these various areas. Therefore, this study aims to determine and compare the infiltration rate in secondary forests, agroforestry, and moor as a basis for directing land use management to preserve the hydrological function of watersheds.

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2. MATERIALS AND METHODS

2.1 Study Area

This study was ccarried out from January to August 2021 in the Toboli watershed, Central Sulawesi, Indonesia. However, the supporting data retrieval study was conducted in 2020, in the production Forest Management Unit (FMU) Model Dolago Tanggunung, Trans Sulawesi Poros Road, Coffee Plantation, Pangi Binangga Nature Reserve Conservation Area, Central Sulawesi. This study area is geographically located at 0⁰43'39" S and 119⁰ 59'17" E with an altitude of 165 m above sea level. Although it is a conservation area, there are still land conversions from primary forest to secondary forest, agroforestry, and moor. This is due to road construction (Trans Sulawesi) from Palu, the capital of Central Sulawesi province to other areas, such as North Sulawesi and Gorontalo. Analysis of soil physical properties was carried out at the Soil Science Laboratory of the Faculty of Agriculture as well as the Forestry Laboratory of the Faculty of Forestry, Tadulako University.

2.2 Sample Collection and Method of Sampling

This study used a survey method, where field observations were carried out at 3 locations, namely secondary forest, agroforestry, and moor. The infiltration rate measurement was performed using a double-ring infiltrometer with 5 repetitions at each location, and the data obtained were calculated using the Horton method. Subsequently, soil samples were collected and analyzed in the laboratory. Sampling was carried out using the undisturbed and disturbed soil sample method with a depth of 0-40 cm and 40-60 cm, respectively. The depth used is related to the infiltration capacity of the area (Wang et al., 2015).

The soil physical properties, such as soil texture, organic matter, bulk density, porosity, and permeability were analyzed using various methods, as shown in Table 1 (Arthur et al., 2013; Worku and Bedadi, 2016).

Table 1: Variable observation of soil physical properties and analysis method

Observational Variables	Method Of Analysis
Soil Texture	Pipette
Organic Matter	Walkeley And Black Say
Bulk Density	Gravimetric
Porosity	Gravimetric
Permeability	Constant Head Permeameter

2.3 Data Analysis

Permeability: This is the ability of the soil to carry water or air, and it is often measured in terms of the water flow rate through the soil with time (cm h^{-1}). Furthermore, it was analyzed using the equation below:

$$K = \left(\frac{Q}{t} \times \frac{L}{H} \times \frac{1}{A}\right) \quad (1)$$

Description:

K: permeability (cm h^{-1})

Q: the amount of water flowing per measurement (ml)

t: measurement time (hours)

L: thickness of soil (cm)

H: Head ring height (cm)

A: ground surface area(cm^2)

Bulk density (BD); bulk density was determined based on the equation below:

$$BD = \frac{\text{absolute dry soil weight}}{\text{Total V}} \quad (2)$$

Description:

V: value of ring volume (cm^3)

Porosity; porosity was determined based on the equation below:

$$Po\,(\%) = \left(1.0 - \frac{\text{bulk density (g/cm}^3)}{\text{particle density (g/cm}^3)} \times 100\%\right) \quad (3)$$

Soil infiltration; The rate was analyzed using the Horton method, which is a time-dependent technique (Abdulkadir et al., 2011; Beven, 2021; Kim et al., 2021).

$$F(t) = fc + (f0 - fc)\, e^{-kt} \quad (4)$$

Description:

f(t): infiltration rate at t- time (cm h^{-1})

fc: constant infiltration rate (cm h^{-1} sec^{-1})

f0: initial infiltration rate (cm $^{h-1}$ sec^{-1})

e: exponential number (2.718)

k: constant (-1/(m log 2. 718)

t : time (sec^{-1})

To obtain k value, the Horton infiltration equation was derived.

$$f = fc + (f0 - fc)\, e^{-kt} \quad (5)$$

$$f - fc = (f0 - fc)\, e^{-kt} \quad (6)$$

Right and left side algorithmed

log (f – fc) = log (f0 – fc) – kt log e

log (f – fc) – log (f0 – fc) = - kt log e

$$t = \left(\frac{-1}{(k \log e)}\right) \log\,(f0 - fc) - kt \log e \quad (7)$$

$$t = \left(\frac{-1}{(k \log e)}\right) \log\,(f - fc) + \left(\frac{1}{(k \log e)}\right) \log\,(f0 - fc) \quad (8)$$

Change to equation:

$$y = mx + c$$
$$y = t$$
$$m = \frac{-1}{k \log e}$$
$$x = \log\,(f - fc) \quad (9)$$
$$c = \frac{-1}{k \log e} \log\,(f0 - fc)$$

So the k value is the equation

$$k = \frac{-1}{m \log e} = \frac{-1}{m \log 2.718} = \frac{-1}{0.4343 \times m} \quad (10)$$

The value of m is the gradient of the graph between the actual infiltration f and log (f – f0).

Classification of the rate was carried out based on the instructions of Soil Conservation Services, as shown in Table 2 (Jury and Horton, 2004).

Table 2: Classification of Infiltration Rate

Criteria	Infiltration Rate (cm h^{-1})
Very Fast	>25.4
Fast	12.7 – 25.4
Rather Fast	6,3 – 12.7
Fairly Fast	2 – 6.3
Rather Slow	0.5 – 2
Slow	0.1 – 0.5
Very Slow	< 0.1

Source: Asdak, 2018

3. RESULT AND DISCUSSION

3.1 Physical Characteristics of Soil

Soil physical properties are related to its shape or conditions, such as texture, structure, bulk density, organic matter, porosity, and permeability. Furthermore, they have a role in plant root activity, including nutrient, water, and oxygen absorption as well as constraint of root movement (Hu et al., 2018). The soil physical properties in the 3 land-use areas are presented in Table 3 below.

Table 3: Physical properties of Soil

Soil physical properties	Land-use			Unit
	Secondary forest	Agroforestry	Moor	
Soil texture	32.1	29.1	27.6	% sandy
	60.3	52.1	42.2	% dusty
	7.6	18.8	30.2	% clay
Texture class	Dusty Clay	Dusty Clay	Loamy clay	-
Bulk density	1.14	1.22	1.75	g/cm^3
Organic matter	2.72	6.35	1.28	%
Porosity	46.17	49.15	28.26	%
Permeability	27.48	12.75	9.83	cm h^{-1}

Table 3 shows that secondary forest and agroforestry land use areas have a dusty clay texture, while moorland has a loamy clay, which influenced their infiltration rates. A soil with fine texture has more dense pores than coarse or sandy soil, and this factor greatly affects the speed of water penetration. The bulk density on the secondary forest, agroforestry, and moor land use areas were 1.14 g/cm^3, 1.22 g/cm^3, and 1.75 g/cm^3, respectively. The existence of repeated pressure on land causes soil compaction, which leads to an increase in the density. This finding is in line with compaction is an important problem because it is related to soil quality for crops, agricultural production, and infiltration rates (Shah et al., 2017). Furthermore, low to medium bulk density is influenced by dusty and sandy textures, which causes an increase in the number of pores. The occurrence of soil compaction increases the value, and this leads to a slow infiltration rate (Irmak et al., 2018). This is consistent that the higher the density, the lower the porosity (Franza et al., 2019). The analysis results showed that the secondary forests, agroforestry, and moor contain 2.72%, 6.35%, and 1.28% organic matter respectively, as shown in Table 3.

A study stated that an increase in soil organic matter led to a decrease in bulk density as well as an increase in porosity (Chaudhari et al., 2013). This condition is advantageous because it causes an increase in the infiltration speed. The secondary forest had a porosity of 46.17%, while 49.15% and 28.26% were recorded in the agroforestry and moor, respectively. The highest value was obtained in the agroforestry land use, which indicates that water can enter the soil faster. A reported that the more porous a soil is, the higher its infiltration rate (Fu et al., 2019). There also revealed that low porosity reduced the rate of water flow (Gopal et al., 2019). Permeability is the ability of the soil to pass water to the lower layers of its profile. Table 2 revealed that highest value of 27.48 cm h^{-1} was recorded in the secondary forest, followed by agroforestry and moor with 12.75 cm h^{-1} and 9.83 cm h^{-1}, respectively. Soil structure and texture play a very significant important role in the high permeability of the soil, which causes an increase in the rate of infiltration. An increased inflow of water into the soil reduces surface runoff as well as erosion.

3.2 Infiltration Rates in Various Land Use

Infiltration is defined as the percolation of water through the soil, and it is an important parameter in hydrological modeling, such as surface runoff, as well as watershed and irrigation management (Singh et al., 2017). Furthermore, the infiltration rate is the amount of water per unit time that enters the soil surface, and low values are obtained when the it is in a dry state. The results showed that there were differences in the rates of the three land use areas, as shown in Table 4.

Table 4: Infiltration Rate of Various Land Use

Time (t) (Sec)	Infiltration Rate (cm h^{-1})		
	Secondary Forest	Agroforestry	Moor
0.00	14	14	14
0.16	10.4	14.2	6.2
0.33	8.5	13.6	4.5
0.50	7.4	10.4	3
0.66	6.4	7.6	1.9
0.83	3.9	5.1	1.7
1.00	3.6	4.3	1.5

The infiltration rate in the secondary forest and agroforestry were included in the rather fast and fast categories, respectively. Vegetation in the secondary forest had a high number of species, but it was not the only factor that affected water inflow. Furthermore, the bulk density in this land-use area was also greater than that of agroforestry, but it had a lower soil porosity. A reported that the increase in the number of cavities in the soil led to a high infiltration rate (Hussain et al., 2020).

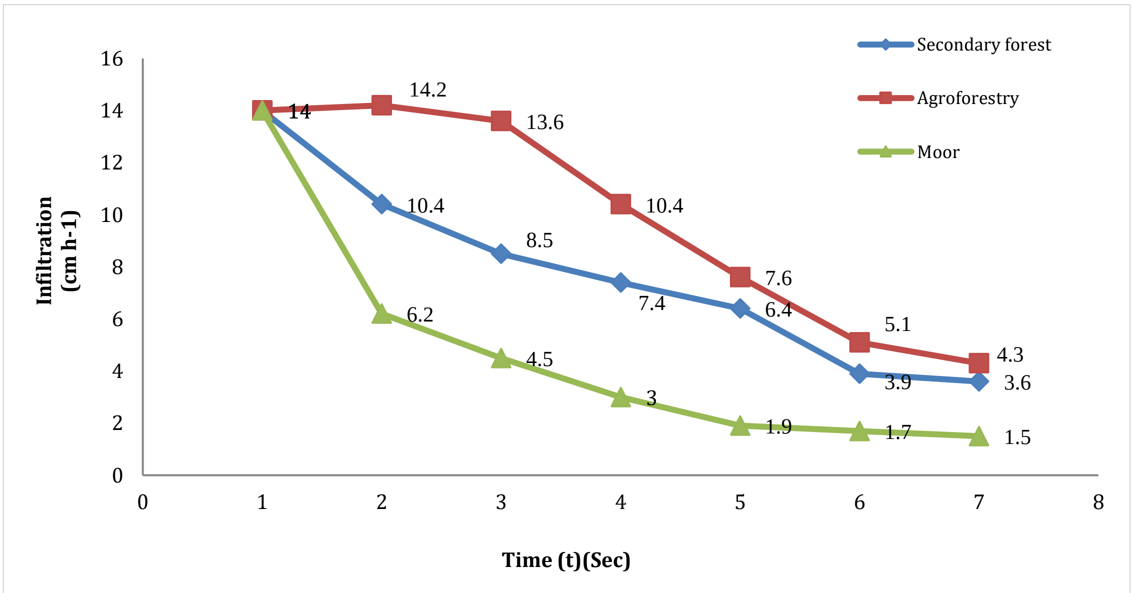

Figure 1: Infiltration rate in secondary forest land, agroforestry, and moor

The highest soil porosity of 49.15% was obtained in the agroforestry compared to secondary forest and moor. The revealed that high values in the soil are directly proportional to the infiltration rate (Ngadisi et al., 2020). Furthermore, the vegetations on agroforestry lands have more than one type of plant with overlapping crowns, which can block the impact (kinetic energy) of falling rainwater, thereby increasing the inflow of water into the soil. A low infiltration rate of 4.73 cmh^{-1} was recorded on dry land compared to agroforestry and secondary forest, which were included in the fast and rather fast categories, respectively, as shown in Figure 2 (Delima et al., 2018). The frequency of tillage in the moorland was higher, and this led to an increase in its bulk density, as well as a decrease in the porosity.

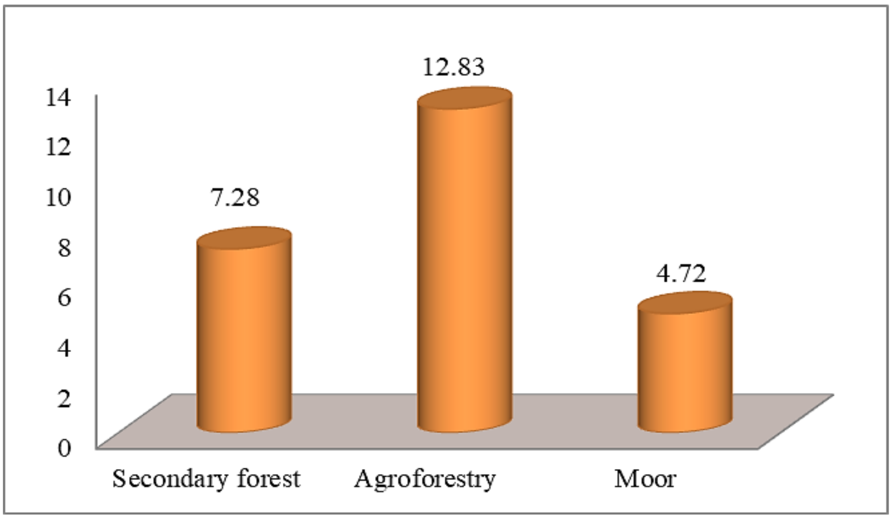

Figure 2: Infiltration rate in secondary forest land, agroforestry, and moor.

Vegetation and litter layers protect the soil surface from direct raindrops that can destroy its aggregates, and cause soil compaction as well as blockage of pores. The condition can also inhibit soil infiltration, thereby leading to soil erosion along with an increase in surface runoff (Darja et al., 2002; Masnang, 2014; Naharuddin et al., 2020). The vegetations on the moorland are few, and their roots are short, hence, they cannot absorb a large amount of water. A study stated that low vegetation can provide open space, and this increases the impact of rainwater, as well as causes low water absorption, and excess runoff (Delima et al., 2018). Infiltration capacity is also influenced by vegetation size, which affects the protection of the soil against erosion, and worsens the physical properties (Telak and Bogunovic, 2020; Tang et al., 2019; Kaloper et al., 2020). Furthermore, the amount of vegetation in agroforestry, including candlenut and teak, led to the low density and high porosity of the area.

4. Conclusion

The highest infiltration rate of 12.83 cm h^{-1} was obtained in the agroforestry land, which was included in the fast category with a dusty clay texture. Furthermore, the secondary forest had the second-largest rate of 7.28 cm h^{-1}, which was included in the rather fast category, with a dusty clay texture. The moor land-use area with a loamy clay soil type had the lowest value of 4.72cm h^{-1}, and it was included in the medium category. Based on the results, infiltration heterogeneity is the most important factor, and it is majorly influenced by land use, especially in moor areas. sustainable soil and water conservation strategies are needed, especially in some forms of land use that can affect the rate of infiltration.

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