Soil properties and infiltration rate in sago palm (*Metroxylon sago*) forest in Rongkong Watershed South Sulawesi

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Abstract. Sago palm, one of the dominant wetland vegetation in the Rongkong Watershed, contributes to groundwater recharge through its ability to pass water into the ground. This study aims to determine the effect of sago forest canopy density on the infiltration rate in the middle and downstream zones of the Rongkong Watershed in South Sulawesi. Other independent variables were soil texture, permeability, bulk density, porosity, soil organic matter, initial soil moisture, water level, air temperature, and air humidity. The relationship between the independent variables on the infiltration rate was analyzed using multiple linear regression. Infiltration rate observed with ponded infiltration method at five density classes of sago forest. The results showed that the infiltration rate in the middle stream increased along with the increase of density classes of sago forests. The downstream, on the other hand, has an insignificant difference between density classes. The result of the regression analysis showed that the coefficient of determination in the middle and downstream zones was 64.5 % and 38.5 %, respectively. The simultaneous test of variable significance in the middle stream shows that the sago forest canopy density, groundwater level, initial soil moisture, and air humidity significantly affect a p-value <0.05.

1. Introduction

Wetlands are marginal lands, but they can support human welfare. Wetlands can slow down water flow and increase groundwater storage. [1] states that wetlands can provide a source of clean water and maintain a diversity of flora and fauna. Groundwater recharge occurs through an infiltration process in which the position of the wetlands is higher than the groundwater level (water table).

One of the vegetation of wetland ecosystem is sago palm, which plays a role in collecting water from the surrounding environment, protecting the area along the river from accumulation due to leaching of material in high altitude areas, increasing the ability of the soil to store water, and preventing flooding [2]. Sago palm has a fibrous root and grows widely in the soil where then helps in water storage. [3] stated that the presence of sago help maintains the continuity of water sources and water flows.
As much as 64% of the world’s sago forests are in Indonesia. The sago forest in Indonesia distributes from Irian Jaya, Bintuni, South Irian, Kalimantan, Sulawesi, and Sumatera [4]. South Sulawesi has the largest sago forest in the Rongkong Watershed (DAS). The community around the forest utilizes sago palm for its starch. Unfortunately, this utilization does not accompany the replanting of sago palm, which causes decreasing the density of sago forest. The effect of sago forest density on the infiltration rate needs to be investigated to support sustainable sago forest management. The results of this study are expected to become a guideline for local governments to promote sustainable sago forest management and the availability of data needed for further research related to sago forests.

2. Methods

2.1. Determination of sago forest density class

2.1.1. Interpretation of sago forest distribution. The map of the sago forest distribution area resulted by processing satellite imagery with a visual interpretation method. The SPOT 2018 imagery has been chosen for its high resolution to help researchers recognizing the sago forest in the Rongkong Watershed. The distribution of sago palm recognizes by its unique characteristic, which is growing in clumps so that the sago can dominate a wide area. Sago forests show a smoother texture at SPOT 2018 imagery than other vegetation. Sago exhibits a darker color than other palm species. According to [5], the order of growing areas from the shoreline is mangrove, nipa, and behind the nipa, there is a large area of sago forest. Sago palm is spread out to an altitude of 700 m above sea level and can still find up to 1000 m above sea level. The accuracy test was carried to determine the accuracy of the image interpretation results using the overall accuracy (OA) method with the following equation.

\[
OA = \frac{X_n}{N} \times 100\%
\]

notation: \(X_n\) = the number of diagonal values of the matrix, \(N\) = the number of matrix samples.

The ground truth points were determined randomly; as many as 65 points were scattered in the middle and downstream zones of the Rongkong Watershed.

2.1.2. Classification of canopy density class of sago forest. The canopy density class of sago forests obtain using the unsupervised classification method. The classification of sago forest canopy density had determined by pixels of the same color radiance into one group. The first step starts with classifying the sago forest map into ten classes then reclassifying it into five density classes. Reclassifying is done by visually comparing the computer analysis and sago forest appearance in the SPOT 2018 imagery. There are five classes of sago forest canopy density, namely: very dense (SR), dense (R), moderate (S), less dense (KR), and not-dense (TR).

Validation of canopy density classes of sago forests uses the hemispherical photography method [6] to capture the percentage of canopy closure in the field. The field photos using a fisheye lens have the RGB color then converted into black and white color. The canopy cover is represented by gray to black pixels, while white pixels represent the part not covered by the canopy. The percentage of canopy cover was analyzed using GIS software. The class of canopy cover density in the field had based on natural boundaries. The result of the canopy closure percentage analysis in the sago forest adjusts to the canopy density class of sago forests.
2.2. Observation of infiltration rate
The observation had held in the middle and downstream zones of the Rongkong Watershed in five canopy density classes. Each density class consists of 5 points so that the total observation points are 50 points. The infiltration rate had measured using the ponded infiltration method. The ponded infiltration method had carried out by placing the ring vertically as deep as 5 cm from the ground surface. The ring is filled with water starting from the outer part of the ring. The infiltration rate records every 10 minutes for 180 minutes. The instrument used for measuring the infiltration rate is a double-ring infiltrometer. A double-ring infiltrometer uses to reduce bias due to lateral flow. In the end, the result of field observation processes with the following equation.

\[
\text{Infiltration rate} = \left( \frac{\Delta H}{t} \times 60 \right)
\]

notation:
\(\Delta H\) = The height of water reduction (mm) each 10 minutes
\(t\) = the interval time of observation (10 minutes). The conversion of minutes to hours multiplied by 6 (hour).

The relationship between infiltration rate and time plots between time (hour) as the x-axis and the infiltration rate as the y-axis.

2.3. Observation of soil properties
The soil properties observed were bulk density, porosity, permeability, soil texture, and soil organic matter. Disturbed and undisturbed soil samples took at ten observation points, one point per density classes in the middle and downstream of the Rongkong watershed. The equation in table 1 uses to analyze the soil sample.

| Soil property | Equation | Notation |
|---------------|----------|----------|
| Bulk Density  | \[
\frac{\text{dry weight}}{\pi r^2 t}
\] |
| Porosity      | \[
1 - \frac{\text{BD}}{\text{PD}} \times 100(\%)
\] |
| Permeability  | \[
\frac{x}{2ndt}
\] |
| Soil texture  | \[
\frac{\text{BDL} + \text{sand weight}}{\text{BDL} + \text{sand weight} + \text{silt weight}} \times 100\%
\] | BD = bulk density, PD = Particle Density (2.65) |
| Soil organic matter | \[
\frac{\text{BDL} + \text{sand weight}}{\text{BDL} + \text{sand weight} + \text{clay weight}} \times 100\%
\] |

2.4. Observation of environmental factors
The observed environmental factors are air temperature, air humidity, initial soil moisture, and water level. Temperature and humidity meters use to measure the temperature and humidity of the air. The initial
soil moisture was measured using a soil analyzer. The water level measurement base on the depth of soil where the saturated zone reached. The identifying of saturating layer held by making a hole using soil drill.

2.5. Multiple linear regression
The influence of sago forest canopy density, soil properties, and environmental factors toward the infiltration rate was analyzed using multiple linear regression with the following equation.

\[ Y = a + b_1x_1 + b_2x_2 + \cdots + b_nx_n \]  

notation:
Y = dependent variable
x = independent variable
a = constant
b = coefficient estimate.

3. Result and discussion

3.1. The distribution of sago forest and the canopy density class of sago forest
The distribution of sago downstream of the Rongkong Watershed is at an elevation of 5 to 30 m above sea level. Sago forest in the middle stream spread at 20 to 100 m asl. The result of 65 ground truth points shows 7 points are not sago forest and 58 points are sago forest. If expressed in percent, the accuracy of the digitization result has a value of 89.23%. [7] revealed that if the image accuracy-test value is more than 85%, the image interpretation is accepted. There are several points where the results of interpreting differ from the field conditions. Several reasons are that the palm family has the same canopy shape, which resembles a star, and conversion of the sago palm forest into a pond has not been updating in the imagery. The analyses of the distribution and density of sago forests show in figure 1 and figure 2.

![Figure 1](image-url)

**Figure 1.** The Map of sago distribution and density class in the downstream of Rongkong Watershed.
Figure 2. The Map of sago distribution and density class in the middle stream of Rongkong Watershed.

The unsupervised classification of the sago forest distribution map in the Rongkong Watershed shows five density classes, namely very dense (SR), dense (R), moderate (S), less dense (KR), and not-dense (TR). The average percentage of canopy closure shows in table 2. Based on the canopy closure percentage, the result of unsupervised classification follows the rank of canopy closure.

| Watershed       | SR (%) | R (%) | S (%) | KR (%) | TR (%) |
|-----------------|--------|-------|-------|--------|--------|
| Downstream      | 80.2   | 77    | 72.4  | 54.4   | 47     |
| Middle stream   | 80.4   | 78.4  | 71    | 57.2   | 56.8   |

3.2. Infiltration rate

The curve of the infiltration rate in figure 3 illustrates the infiltration process in the middle and downstream zones of the Rongkong Watershed at five density classes. The curves show the infiltration process starting when the infiltration reaches its highest rate at the beginning of the observation, reaching saturation and recovering from saturation. The actual infiltration rate downstream of the Rongkong watershed did not show any significant difference between each density class. The infiltration rate was relatively stable from the initial minute till the last minute of observation. Meanwhile, the infiltration rate curve in the middle zone shows the difference between density classes. The denser the canopy density of the sago forest, the more water it can infiltrate into the soil. The downstream and middle-streams of the Rongkong Watershed show that the time required for recovery from saturation is in line with the sago forest density. The higher the canopy density class of the sago palm forest, the faster the recovery time.
Figure 3. The infiltration rate curve in downstream (a,c,e,g,i) and middle stream (b,d,f,h,j) of Rongkong Watershed. The curve annotation: Watershed zone; canopy density class; n repetition. The middle stream zone = T; the downstream zone = H. Canopy density classes: very dense (SR), dense (R), moderate (S), less dense (KR), and not dense (TR). The repetition (1 till 5).

3.3. Soil properties

Soil properties such as soil texture, permeability, bulk density (BD), porosity, and soil organic matter, participate in passing the water into the ground. The analysis of soil samples for five density classes in the middle and downstream of the Rongkong watershed summarize in table 3.

The soil texture analysis showed the downstream of the Rongkong Watershed in the five canopy density classes of sago forest is in the clay category. Moreover, the percentage of clay in S, KR, and TR classes > 60% causes the soil at these densities sensitive to compaction. Meanwhile, the middle stream shows more diverse texture classes. The clay category finds in the SR and S classes. Soils that are compacted-sensitive have an impact on slowing the infiltration rate in the area. [8] stated that the clay fraction > 60% also increases soil resistance at the bottom layer so that it is difficult to penetrate by water.

Table 3. Soil properties in middle and downstream zone of Rongkong Watershed.

| Zone            | Soil Properties | SR  | R  | S  | KR | TR |
|-----------------|-----------------|-----|----|----|----|----|
| **Downstream**  | Permeability (cm/h) | 0   | 0  | 0  | 1  | 0.08 |
|                 | Soil texture    | clay | clay | clay | clay |
|                 | Soil organic matter | 1.457 | 2.76 | 1.32 | 1.41 | 1.46 |
|                 | Bulk density (g/cm³) | 1.06 | 0.97 | 1.09 | 1.05 | 0.95 |
|                 | Porosity (%)    | 60.15 | 64.35 | 58.93 | 60.32 | 63.97 |
| **Middle stream** | Permeability (cm/h) | 0.07 | 0  | 0.06 | 0.65 | 0  |
|                 | Soil texture    | clay | silty clay | clay | silty loam | loam |
|                 | Soil organic matter | 2.55 | 2.19 | 2.13 | 2.33 | 1.68 |
|                 | Bulk density (g/cm³) | 0.73 | 0.88 | 0.81 | 0.93 | 1.08 |
|                 | Porosity (%)    | 72.55 | 39.21 | 69.45 | 64.5 | 58.86 |

*SR = very dense
*R = dense
*S = moderate
*KR = less dense
*TR = not-dense
The content of soil organic matter in the downstream and middle stream categorize into medium to high ranged from 1-2 and 2-4, respectively. Based on the result of organic matter content shown in table 3, the SR, S, KR, and TR classes downstream are medium, while the R class is high. The organic matter content in the middle stream of the Rongkong watershed is in the high category, except for the TR class. The presence of soil organic matter can improve soil aggregate and structure, and it prevents soil from compacting so that there is room for water to pass. Organic matters can provide sufficient macropores. They help to recharge more water and to increase water retention capacity [9].

The BD values in the downstream Rongkong Watershed are ranging from 0.95 - 1.06 g cm-3. [10] states that soil with a BD value less than one has moderate to high soil organic matter. The soil organic matter also plays a role in reducing BD. The highest BD value finds in the S class and the lowest in the TR class. The middle stream of the Rongkong watershed sequentially has BD starting from the lowest to the highest in the SR to TR class. The higher the BD value, the less the number of macropores in the soil. The reduction in macropores makes it difficult for the ground to pass water.

Porosity is high downstream of the Rongkong Watershed. However, the permeability value falls into a very slow category. The highest porosity in the middle stream of the Rongkong Watershed finds in the SR class. The S class has the second largest percentage value, followed by R, KR, and TR class. According to [11], the greater the percentage of clay fraction, the more micropores. Micropores dominate soils with a clay texture and contain only a few macropores.

3.4. Multiple linear regression

3.4.1. Middle rstream of Rongkong Watershed. Three main categories of the independent variable, namely the canopy density of sago forest, soil properties, and environmental factors, were examined. The only independent variable that has a significant effect on the infiltration rate is the water level. The water level is a characteristic of the hydrological period in a wetland that plays a primary role in the wetland ecosystem [12].

| Model | Unstandardized coefficient | Standardized coefficient | t | Sig. |
|-------|----------------------------|--------------------------|---|------|
|       | B                          | Std. Error               | Beta |      |      |
| Constant | 8.211                     | 1.463                    | 5.612 | 0.000 |
| Water level | -0.029                    | 0.008                    | -0.883 | -3.662 | 0.003 |
| Initial soil moisture | -0.301                    | 0.157                    | -0.463 | -1.921 | 0.077 |

The independent variables simultaneously test toward infiltration rate. The test shows that initial soil moisture, air humidity, water level, and canopy density of sago forests significantly affect the infiltration rate with a value of 0.025. [12] explained that wetland ecosystems form between the interaction of three main components, hydrology, physicochemical environment, and biota. Specifically, [13] states that the vegetation cover and groundwater content affect the infiltration rate.
Table 5. The simultaneous test of independent variables on the infiltration rate. The variables that significantly influence the infiltration rate are the initial soil moisture, air humidity, water level, and the canopy density of sago forests.

| Model      | Sum of Squares | df | Mean Square | F    | Sig. |
|------------|----------------|----|-------------|------|------|
| Regression | 10.054         | 4  | 2.514       | 4.299| 0.025|
| Residual   | 6.431          | 11 | 0.585       |      |      |
| Total      | 16.485         | 15 |             |      |      |

The observed variables affecting infiltration rate are initial soil moisture, air temperature, permeability, porosity, soil texture, water level, and canopy density of sago forests. The results of multiple linear regression showed a value of R2 by 0.645. This value means that the independent variable influence the infiltration rate by 64.5%.

3.4.2. Downstream of the Rongkong Watershed. Results of the partial and simultaneous tests showing in table 6 and table 7 have a significant value bigger than 0.05. This value indicates that all the independent variables affect the infiltration rate weakly.

Table 6. A partial test of the independent variable on the infiltration rate.

| Model      | Unstandardized coefficient | Standardized coefficient | t    | Sig. |
|------------|-----------------------------|--------------------------|------|------|
|            | B                           | Std. Error               | Beta |      |
| Constant   | 4.846                       | 1.094                    | 4.429| 0.000|
| Permeability| -1.148                      | 0.641                    | -0.445| -1.790| 0.091|
| % sand     | -0.102                      | 0.078                    | -0.325| -1.307| 0.209|

Table 7. The simultaneous test table. The variables with the highest value were air humidity, % sand, air temperature, and permeability.

| Model      | Sum of squares | df | Mean square | F    | Sig. |
|------------|----------------|----|-------------|------|------|
| Regression | 7.711          | 4  | 1.928       | 1.770| 0.187|
| Residual   | 16.334         | 15 | 1.089       |      |      |
| Total      | 24.045         | 19 |             |      |      |

The value of R2 of the Rongkong Watershed downstream is only 0.385. This value means that the independent variables only affect the infiltration rate by 38.5%. [12] listed four types of freshwater wetlands. One of them is the surface water slope that infiltrates a limited amount of water. This type of wetland corresponds downstream of the Rongkong watershed that builds from alluvial soil and is close to the main river.
4. Conclusions
The infiltration rate in the middle and downstream of Rongkong Watershed is influenced by the canopy density of sago forest, soil properties, water level, air temperature, air humidity, and initial soil moisture in the coefficient of determination ($R^2$) by 64.5% and 38.5%, respectively. The simultaneous significance test of variables in the middle stream of the Rongkong watershed shows that the canopy density of sago forest, water level, initial soil moisture, and air humidity significantly affects a p-value < 0.05. The infiltration rate curve in the middle zone of the Rongkong watershed increases with the increase of the canopy density class of sago forests.

The magnitude of the difference in the coefficient of determination between sago forests in the middle stream and downstream zones leaves a question regarding how each independent variable interact with each other in determining the infiltration rate. The significant effect of water level on the infiltration rate is the starting point for developing in-depth research on the characteristics of the hydroperiod of sago forests in specific sites.

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