The role of the mahogany tree (*Swietenia macrophylla* King) on quantity and quality of water that fall below the canopy

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Abstract. Mahogany trees (*Swietenia macrophylla*) are often planted in urban forests area. This shady-crowned tree has a role in controlling the quantity and quality of rainwater that falls to the ground. Mahogany trees also affect the quality of rainwater through interception, fall, and stemflow. The purpose of this research was to determine the impact of the interception process, such as throughfall and stemflow, on changes in rainwater quality of the mahogany tree. The Data that needed to be measured were tree dimension, rainfall interception, and rainwater quality. Interception measurement was performed by calculating the number of throughfall and stemflow in one month-measurement. While the measurement of rainwater quality was measured once in the laboratory. These water quality measurements include Electrical Conductivity (EC), hardness, the content of Elements Ca, Mg, Na and K, and pH concentrations. The results based on the total area of the crown showed that mahogany had an interception value of 18.088%. In the throughfall measurement, the mahogany has a throughfall of 81.799%, while the amount of the stemflow is only 0.113%. The correlation of interception values, throughfall, and stemflow with rainfall are in general positively correlated. That means the higher rainfall water will increase the number of interception, throughfall, and stemflow. The results on water quality measurement explain that Ec value in rainwater interception was increased compared to water produced from rainfall in mahogany trees. It also has the same condition in hardness measurement. In pH measurements, the interception of rainwater has less pH when compared to direct rainfall water. In addition, the content of Elements Ca, Mg, K, and Na in Stemflow and Throughfall water have more numbers than rainfall itself.

1. Introduction

The urban area is an open system, both physically and economically, dynamic or temporary. The existence of an urban area itself has a purpose in fulfilling the needs of the population in it so that they can survive and continue their lives properly. Therefore, urban areas will continue to develop as centers of trade, residential services, government, culture, education, and recreation over time. Recently, the rate of population growth in urban areas has increased rapidly from year to year. The increasing number of populations in urban areas will lead to more utilization of natural resources and the environment. One of the consequences is the increasing use of land resources in urban areas in the form of Green Open Space which is converted into built-up land. The rapid development of urban areas every year causes changes in land use, which results in an increased ground runoff, thereby increasing the risk of flooding [1].

The existence of green open spaces in urban areas has various benefits, one of them being as a
provider of urban ecological functions. Some of the ecological functions of green open space include aesthetic functions, germplasm conservation, recreation, CO2 absorption, protection of the water cycle, and protection from disasters such as floods or erosion/landslides [2]. Green Open Space itself is a part of green infrastructure in the form of an interconnected network between the function of preserving and ecosystems regulator as well as providing benefits to humans [3]. Green open space is known as a part of the city's identity and can maintain the city’s environmental quality [4]. Meanwhile, according to the Draft Technical Guidelines for East Java (2015), one of the functions of green open space is as the rainwater absorber. Green Open Spaces as a rainwater absorber is a space that planted with trees or grass which can improve soil structure or can hold rainwater above the canopy, so it does not become surface run off. Green open space in the form of the forest is known to be able to intercept rain and reduce surface runoff [5].

In addition, it is also known that the nutrient cycle in the forest is strongly influenced by precipitation, which is rainwater carries the nutrients needed to fertilize the soil [6]. Recent studies have shown that rainwater from stemflow and throughfall is also able to enrich the organic elements carried by rainwater [7]. Of course, this evidence adds value to the ecological function of urban forests, which intercept the rain and enrich the nutrients carried by rainwater to the soil through the stems and leaves.

For this reason, it is important to study the characteristics or types of trees that are common in green open spaces and can intercept rainwater well to reduce the surface runoff. One of the trees commonly found in green open space and which will be the main focus of the object in this research is the Mahogany tree (*Swietenia macrophylla*). Mahogany trees (*S. macrophylla*) are known to have a fairly large canopy and have a role in controlling the quantity and quality of rainwater that falls to the ground. Mahogany trees affect the quality of rainwater through the process of interception, throughfall, and stemflow. In addition, research on the quality (nutrient content) of rainwater intercepted by Mahogany trees is also important to know before further testing is carried out to see the impact of tree interception on the soil nutrient. This research aimed to determine the amount of interception, throughfall, and stemflow and their correlation with precipitation.

2. Research Method

2.1. Time and Location

This research was carried out at ITB Jatinangor, Jl. Let. Jen. Purn. Dr. (HC) Mashudi No. 1, Desa Sayang, Kec. Jatinangor, Sumedang Regency, West Java (figure 1). Overall, this research was held from 2 February - 9 April 2020. The time of the study was divided into 2 data collection periods, namely interception and rainfall data collection, which was held for a full month from 2 February – 3 March 2020, and testing of water quality samples was held from 15 March – 9 April 2020.
2.2. Data collection
The primary data collected can be divided into three data groups: tree dimension data, interception and rainfall data, and water quality data. The tree species that will be tested in this study is the Mahogany Tree (*Swietenia macrophylla*). Then, three samples were taken with purposive sampling by selecting individuals whose condition was relatively the same (healthy, canopy conditions, and in the same age class).

The dimension data was collected on each tree with the parameters measured were trunk diameter, branch-free height, total height, and canopy area. Canopy area is not the same as leaves area, so it was measured by calculating the area of a globular which radius is taken from the average tree canopy radius, and the height is taken from total tree height minus branch-free height. The tools used in measuring the dimensions of this tree include a roll-meter, compass, haga hypsometer, and measuring tape.

Rainfall data was measured using a manual ombrometer made of plastic jerry cans and funnels. This ombrometer is placed in an open location and free from the shade of trees or buildings that may block the entry of rainwater directly into the ombrometer. This rainfall measurement is carried out every morning at around 08.00 WIB if it rains on the previous day.

Meanwhile, the measurement of rain interception is divided into two measurement activities, throughfall, and stemflow. Throughfall water is measured using a manual ombrometer such as rainwater measurement. The difference is the placement of this tool is placed right under the canopy of the test tree. The manual ombrometer used in the measurement of Throughfall was four pieces per test tree by placing it in every four cardinal directions in the middle of the crown radius. Meanwhile, the stemflow measurement is carried out using a hose that is wound from top to bottom around the test tree where one of the misplaced lower at the bottom (ideally 40-45°).

In the water quality test, seven parameters are measured, which can be grouped into two measurement categories. The first one is the measurement of chemical properties consisting of pH, the content of Magnesium, Calcium, Natrium, and Kalium. The other one is a measurement of the physical properties of water that only tests the ability of the electric conductivity and the hardness of the water. For the water quality analysis, a sample of water is taken from the last three rainy days in the rainfall and interception measurement.

2.3. Data analysis
According to Lee [5], rain interception by trees cannot be directly measured in the field. Therefore there is an equation used to find the amount of interception by trees. Quantitatively, the intercept is the difference between rainfall and the amount of throughfall and stemflow, and the calculation was using...
equation (1).

\[ I_c = P - (T + S) \]  

Where:
- \( I_c \): Interception (mm)
- \( P \): Precipitation (mm)
- \( T \): Throughfall (mm)
- \( S \): Stemflow (mm)

Thus, to determine the magnitude of tree interception, it is necessary to first determine the amount of rainfall through equation (2), throughfall through equation (3), and stemflow through equation (4) from the tree under study. The equation in calculating rainfall, throughfall, and stemflow can be seen below:

\[ P = \frac{V}{A} \]  

(2)

Where:
- \( P \): Precipitation (mm)
- \( V \): Volume (mm³)
- \( A \): Area (mm²)

\[ T = \frac{V}{A} \]  

(3)

Where:
- \( T \): Throughfall (mm)
- \( V \): Volume (mm³)
- \( A \): Area (mm²)

\[ S = \frac{V}{Ac} \]  

(4)

Where:
- \( S \): Stemflows (mm)
- \( V \): Volume (mm³)
- \( Ac \): Crown Area (mm²)

A simple linear regression test was performed to look for the relationship between rainfall and interception, rainfall with throughfall, and rainfall with stemflow. The linear equation shown in equation (5) [8].

\[ \hat{Y}_i = a + bX \]  

(5)

Where:
- \( \hat{Y}_i \): Rainfall
- \( a \): Constant
- \( b \): Regression coefficient
- \( X \): Throughfall/Stemflow/Interception

To find the value of the closeness between the variables \( X \) and \( Y \), it is important to find the value of \( r \) first through equation (6).

\[ r = \frac{\Sigma(xy) - (\Sigma x)(\Sigma y)}{\sqrt{\Sigma(x^2) - (\Sigma x)^2} \sqrt{\Sigma(y^2) - (\Sigma y)^2}} \]  

(6)

Where:
- \( r \): Correlation coefficient
3. Results and discussion

3.1. Tree dimension
Dimensional measurements and identification of stem and leaf morphs can help determine the factors affecting stemflow, throughfall, and rain interception. The record said it is known that the amount of rainwater intercepted by plants varies depending on the type of plant leaves, canopy shape, wind speed, radiation/sunlight, temperature, and humidity.

In table 1 it is known that Mahogany or *Swietenia macrophylla* is a species that is physically relatively small in size, with a trunk diameter of only 28-37 cm, a branch-free height of about 2 m, and a canopy area measuring > 80 m². However, please note that this can happen because the age of the Mahogany tree being tested is still young (+5-7 years).

| Species       | No | Diameter (cm) | Branch/Free Height (m) | Total Height (m) | Canopy Area (m²) |
|---------------|----|---------------|------------------------|------------------|------------------|
| *Swietenia macrophylla* | 1  | 37.261        | 2                      | 14               | 88.203           |
|               | 2  | 32.803        | 2                      | 11               | 60.790           |
|               | 3  | 28.862        | 1.85                   | 12.5             | 52.703           |

3.2. Throughfall, stemflow, and interception
The values of throughfall, stemflow, and precipitation were obtained from measurements for a full month (30 days) which found 18 rainy days. In figure 2 below, the percentage values of throughfall, stemflow, and an interception on mahogany trees are presented. It can be observed based on the graph, the throughfall value on mahogany trees has an average of 81.799%. Meanwhile, the results of subsequent observations found that the mahogany tree had an average stemflow value of 0.113%. Furthermore, the results of the interception calculation presented in figure 2 below show that mahogany trees have an intercept percentage of 18.088% from the total rainfall. According to Bruijnzeel [9], the amount of interception in the tropics ranges from 10% to 35% of the total rainfall.

The difference in the value of the throughfall is generally due to the different conditions of the canopy of each individual. One of the factors that affect the value of the throughfall is the canopy storage capacity. If the canopy storage capacity is still greater than the rainfall, the rainwater will be accommodated entirely by the canopy, and vice versa, if the rainfall is greater than the capacity of the canopy, there will be saturation in the canopy, resulting in throughfall. Mahogany trees with a fairly large throughfall have a relatively small density of canopy area, which means that rainwater can fall
directly to the ground surface through gaps in the canopy. This indicates that the throughfall will decrease in line with the increasing density of the canopy or forest vegetation stands [10]. In addition, it is also known that the size of the canopy closure area can affect the value of the throughfall [11]. The average throughfall on this tree shows a value of 81.799%, which indicates that the vegetation conditions at the study site are dense enough. This was because at locations without canopy or with low crown density, the throughfall could reach 99%, and it could decrease to 90% to 80% at locations with medium and dense crown cover [10].

The amount of stemflow is largely determined by the trunk structure of the tree species. The stem structure includes the surface of the bark and the branching system. Stemflow is consistently greater in trees with a relatively smooth trunk texture [5]. Because on a smooth trunk, the flow of water in the trunk will be faster and smoother than on a tree with a rough trunk surface, the flow of water in the trunk will be hampered [12]. The results of field observations provide an illustration that the trunk surface condition of mahogany trees with deep grooves on the trunk surface has a very small stemflow value. Besides being influenced by the characteristics of the stem structure, stemflow is also influenced by the storage capacity of the canopy.

Similar to throughfall, rainwater will be stored first in the tree canopy, when it has reached the saturation point of the canopy capacity, then the water will fall into throughfall, and if heavy rain continues, then some of the water will fall through the branches to the tree trunk as a stemflow [13].

Similar to throughfall and stemflow, interception had a significant relationship to the storage capacity of the canopy. The storage capacity of the canopy itself is the amount of water needed to wet the canopy until it is saturated, and then the water would fall to the soil surface [14]. The amount of canopy storage capacity is influenced by LAI (Leaf Area Index), width, density, and thickness of the canopy. The age of a tree will greatly affect the level of canopy density. The denser the canopy, the higher the intercept value. This is thought to make the mahogany interception value tend to be small because the age of the mahogany tree is still thought to be very young.

### 3.3. Correlation between precipitation and throughfall, stemflow, and interception

From the 30 days of precipitation observation, there were 18 rainy days, the results of which are presented in figure 3 below. Based on the table, it can be seen that the highest rainfall occurred on the 4th rainy day (February 8th), with a rainfall of 7,133 mm. On the same day, the number of the interception also experienced the highest value which is 25.46 mm.

![Graph of precipitation and interception measurement results.](image)
Based on the graph generally, the value of the interception is significantly influenced by the size of the rain that happens. Because the interception value is strongly influenced by the characteristics of the rain, automatically, the amount of throughfall and stemflow is also influenced by the characteristics of the rain. This is in accordance with the statement of Irmas [15] that the size of the interception is influenced by the nature of the rain itself (size, intensity, and duration). It was further explained that the higher the rainfall, the higher the water that will be intercepted. Thus, the higher rainfall will generally increase the amount of water that falls through the canopy and stem. However, we still see an anomaly in 10-11th rainy-day that the interception value is low even though the precipitation is pretty high. It is because windspeed also affects the interception value, and it could be that the wind speed greatly affects the interception. However, the measurement of wind speed and its direction is not accounted for in this research. The relationship between precipitation/rainfall with an interception, throughfall, and stemflow, in general, can be described by a simple linear equation. For this reason, in analyzing the relationship between precipitation and interception, throughfall, and stemflow, a linear regression equation model was used, which is presented in figure 4, figure 5, and figure 6.

Figure 4. Graph of relationship between precipitation and throughfall.

Figure 5. Graph of relationship between precipitation and stemflow.
3.4. Precipitation and interception’s water quality

There were seven parameters of water quality that had been tested that can be divided into two categories, physical properties of water, which include electrical conductivity and hardness, and tests of chemical properties of water including pH levels and chemical elements such as Ca, Mg, Na, and K. In table 2 the results of the measurements are presented, where the tested trees have measured from their throughfall and stemflow water. While the quality of original rainfall water is a control sample as a comparison of changes in water quality that occur after an interception.

| No. | Parameter | Unit | S. macrophylla | Stemflow | Throughfall | Rainfall |
|-----|-----------|------|---------------|-----------|-------------|----------|
| 1   | Electrical Conductivity | µS/cm | 98 | 300 | 91.1 |
| 2   | Hardness | mg/L | 16.8 | 50.8 | 6.32 |
| 3   | Potassium (Titration) | mg/L | 4 | 12.4 | 1.6 |
| 4   | Magnesium (Titration) | mg/L | 1.04 | 6.2 | 0.56 |
| 5   | Dissolved Sodium | mg/L | 2.15 | 0.682 | 0.253 |
| 6   | pH | | 5.8 | 6.25 | 6.57 |
| 7   | Dissolved Kali | mg/L | 5.47 | 39.3 | 2.96 |

The table 2 shows that the electrical conductivity of liquids in rainfall (control) is 91.1 µS/cm high. Compared to this number, mahogany is a tree that can significantly increase the electrical conductivity of original rainwater. The highest increment in electrical conductivity occurred in the throughfall, where the electrical conductivity was 308 µS/cm or increased by 216.9 µS/cm. Electrical conductivity is a numerical description of the ability of a liquid to carry an electric current. Therefore, the more dissolved salts that can be ionized, the higher the electrical conductivity value produced. Electrical conductivity is also closely related to the type of electrolyte solution contained in it, whether a weak
electrolyte or a strong electrolyte. That is why the electrical conductivity of the mahogany canopy has a high electrical conductivity value because of the high Kalium content in the solution. Please note that Kalium in water can form KOH compounds which are strong electrolytes. Therefore, the condition of electrical conductivity can be a reference for the level of salinity of a liquid because the higher the electrical conductivity value, then the higher the electrolyte value, which means the higher the salt content contained in it [16]. Of course, it is clear that if the salinity of the soil is high, it will be difficult for plants to absorb water and other nutrients from the soil. For this reason, the level of soil salinity needs to be controlled to maintain soil fertility.

![Chemical Content (mg/L)](image)

**Figure 7.** Chemical content of Na, K, Ca, and Mg in Stemflow, Throughfall, and Rainfall.

The graph shown in figure 7 shows the chemical elements' content, which include Ca, Mg, Na, and K in rainfall water and Stemflow or Throughfall water in mahogany trees. The graph above shows that the elements Ca, Mg, Na, and K in general increased compared to those contained in the rainfall (control). So it can be concluded that the test tree can enrich the chemical elements carried by rainwater, both through leaves as throughfall and stems as stemflow. These results are also in line with research conducted by Dasch [17] that the elements carried by water after passing through the tree canopy contain higher Ca, Mg and K elements than those in ordinary rainfall. The higher metal ions found in intercepted water compared to direct rainwater indicated that tree vegetation was able to absorb pollutants in the air [18].

![Changes in the Chemical Content of Ca, Mg, Na and K](image)

**Figure 8.** Changes in the chemical content of Ca, Mg, Na, and K.
The graph shown in figure 8 provides an overview of the chemical element changes that occur in mahogany trees. From the changes in the four elements above, it can be concluded that the mahogany tree is significant in enriching the chemical elements in rainwater. Furthermore, to see its effect on soil nutrient conditions, it is necessary to analyze the soil's infiltration, surface runoff, and chemical properties so that the results regarding the effectiveness of interception in enriching soil nutrients can be explained clearly.

![Percentage of pH Decrement](image)

**Figure 9.** Percentage of pH decrement.

The graph in figure 9 shows the percentage decrement of the pH of rainfall to rainwater that has been intercepted through the throughfall and stemflow. Overall, the pH value of rainfall and intercepted water by mahogany trees show the acidic nature of the solution (<7). Based on observations, it is also known that the pH is generally decreased after being intercepted by the tree. This means that rainwater will become more acidic after being intercepted by the tree. The most significant decrement occurred in the stemflow of the mahogany tree, where the decrement occurred in the range of 11.6-11.7% or from pH 6.57 to 5.8. Meanwhile, the decrement of pH tends to be stable in the throughfall with a percentage decrement of 4.9% or from pH 6.57 to 6.25.

4. Conclusion

The value of the throughfall on the mahogany tree is 81.7%, while the stem flow is 0.113%. Then on interception, the mahogany tree has an interception ability of 18%. The relationship between precipitation and throughfall generally shows a positive correlation with 95% (very strong) value. Then, the relationship between precipitation and stemflow shows a positive correlation with the R-value on mahogany of 35%, which means that the closeness of the two variables is weak. The relationship between precipitation and interception also shows a positive correlation with the R-value of 60% (strong correlation). In general, there is an addition to water quality in terms of its chemical content (Ca, Mg, Na, and K) in the throughfall and stemflow when compared to ordinary rainwater. On the other hand, the pH conditions of the Throughfall and the stemflow were decreased from the rainwater conditions.

Mahogany trees affect the quality and quantity of water that pass the tree canopy through a mechanism called interception. With the condition of a wide and dense canopy and a rough trunk, this tree's interception ability is quite high. In addition, the chemical processes that occur in the leaves and stems when it rains also make the rainwater that passes through mahogany will increase its chemical elements.

5. References

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