INVESTIGATION OF HYDROLOGICAL CAPACITY OF COFFEE PULP AND HYDROGEL AS BIOPORE FILLER IN RAIN GARDEN IN GREEN INFRASTRUCTURE, JALAN BARU HAMLET, NORTH SUMATRA

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ABSTRACT

Climate change and urbanization have increased surface runoff in Jalan Baru Hamlet, North Sumatra, due to low soil infiltration capabilities. This study aims to investigate the hydrological capacity of coffee pulp, hydrogel, and a combination of the two as biopore filler media in rain gardens as part of the implementation of green infrastructure. The experiment was carried out using five media variations, namely 100% hydrogel, 100% coffee pulp, and a combination of hydrogel–coffee pulp with a ratio of 75%:25%, 50%:50%, and 25%:75%. The parameters analyzed included water absorption rate and water absorption capacity at immersion times of 5, 10, and 15 minutes.

The results showed that 100% hydrogel had the highest hydrological performance with an absorption rate of 40.34 g/g/min and an absorption capacity of 252.42 g/g. In contrast, 100% coffee pulp showed the lowest value with an absorption rate of 0.77 g/g/min and an absorption capacity of 5.15 g/g. Increasing the proportion of hydrogels in mixed media has been shown to significantly improve water absorption ability. The combination of 75% hydrogel: 25% coffee pulp produces an absorption capacity of 222.50 g/g, while the combination of 25%: 75% produces a capacity of 80.57 g/g.

The combination of 50% hydrogel: 50% coffee pulp produces an absorption rate of 24.99 g/g/min and an absorption capacity of 134.48 g/g, and demonstrates the best balance between water retention, absorption stability, and ecological benefits. Coffee pulp plays a role in increasing the porosity of the medium and supporting the improvement of soil structure through the decomposition of organic matter, while hydrogel functions as a water retention medium with the ability to absorb and release water gradually. In addition to increasing water infiltration and retention capacity, the use of coffee pulp also supports the reduction of local organic waste and the application of circular economy principles. Thus, the combination of hydrogel–coffee pulp 50%: 50% is recommended as the optimal biopore filler medium for rain gardens because it has stable hydrological performance, is environmentally friendly, economical, and has the potential to support the sustainability of green infrastructure systems in controlling urban surface runoff.

Keyword: Biopore, Coffee Pulp, Green Infrastructure, Hydrogel, Rain Garden

INTRODUCTION

Climate change has triggered an increase in rainfall in Indonesia. Data from the Meteorology, Climatology, and Geophysics Agency (BMKG) shows an increasing trend of rainfall in the North Sumatra region, which has the potential to trigger hydrometeorological disasters such as floods and landslides (BMKG, 2022). This hydrological pressure is further exacerbated by rapid changes in land cover. The conversion of porous green land into impermeable surfaces, such as roads and settlements, reduces the infiltration ability of groundwater and significantly increases the volume of surface *runoff* (Fletcher *et al.,* 2015).

Jalan Baru Hamlet, North Sumatra, is a real example of a location that faces this problem. Although visually still dominated by green landscapes, this area is vulnerable to waterlogging that causes road damage. Local soil conditions with a low infiltration rate, combined with high rain intensity, cause rainwater to not be able to permeate optimally and collect as inundation on the road surface.

Conventional solutions such as the construction of concrete drainage systems have fundamental drawbacks: high costs, only move problems downstream, as well as contributing to ecological fragmentation (Fletcher *et al.,* 2015). As a more sustainable alternative, *the concepts of Green Infrastructure* (GI) and *Low Impact Development* (LID) offer the philosophy of managing rainwater at its source by mimicking natural hydrological cycles. *Rain gardens*, as one of the GI components, have been shown to be effective in capturing runoff from impermeable surfaces and managing them through temporary retention and infiltration into the soil (Burszta-Adamiak *et al.,* 2023).

The effectiveness of a *rain garden* depends heavily on the characteristics of the media that makes it up. In Indonesia, biopore infiltration hole (LRB) technology is widely known, but the use of conventional organic matter often has limited absorption capacity and decomposition speed (Anggreni *et al.,* 2023). Based on this knowledge gap, this study proposes innovation by utilizing local agricultural waste *(coffee pulp)* and cutting-edge water-absorbing materials *(hydrogel).* North Sumatra as the second largest coffee producer in Indonesia produces coffee husk waste in very abundant volumes that have not been utilized optimally (BPS North Sumatra, 2023).

The objectives of this study are: (1) to measure and analyze the value of water absorption rate and water absorption capacity from biopore media consisting of *coffee pulp, hydrogel,* and their combinations through experimental testing; (2) compare and determine the combinations of materials that produce the highest and most stable hydrological capacity for applications as biopore fillers.

LITERATURE REVIEW

Green Infrastructure dan *Rain Garden*

Green infrastructure is defined as a strategic framework to ensure environmental sustainability through green open space planning and the preservation of natural ecological processes, such as hydrological cycles, soil conditions, and surface flows (Widyaputra, 2020). According to *the Environmental Protection Agency* (EPA, 2025), green infrastructure optimizes development cost efficiency, manages the impact of rainfall, and provides multifunctional benefits for the environment, economy, and society.

A rain garden is a natural catchment area designed to resemble a sunken garden, which functions to accommodate and harvest rainwater runoff from the roofs of buildings, roads, and other impermeable surfaces. Hydrologically, this system works by temporarily holding water in the basin, then allowing water to seep into the ground, thereby lowering the volume of runoff and the load on the city's drainage system (Prince George's County, 1993). *Rain gardens* are also called bioretention areas that consist of a combination of soil, leaf litter, and vegetation to facilitate filtration, infiltration, and evaporation (Bannerman, 2003). The research of Burszta-Adamiak *et*

al. (2023) shows that a full-scale *rain garden* is able to manage 100% of incoming *runoff* without causing overflow, even in very high-intensity rainfall.

Biopores and Their Role in Water Infiltration

Biopores are natural spaces or pores in the soil that are formed due to the activity of soil organisms such as worms, termites, and plant roots (Setiawan *et al.,* 2018). Biopore Infiltration Hole (LRB) technology is an effective solution in rainwater runoff management, especially in urban areas with minimal infiltration areas. Biopore holes are generally made vertically with a diameter of 10–30 cm and a depth of 30–100 cm, then filled with organic matter (Pratiwi *et al.,* 2021). In addition to increasing water infiltration, organic matter is a food source for soil organisms that expand the soil pore tissue through biological activity.

Characteristics of Hydrogel as a Biopore Filler

Hydrogel is a three-dimensional hydrophilic polymer network that has a high ability to absorb, store, and release water reversibly (Sannino *et al.,* 2009). The *structure of the hydrogel* is composed of polymer chains that are cross-linked and form nano-sized cavities, so that they are able to hold water molecules through polar group interaction and hydrogen bonding (Ostrowska-Czubenko & Gierszewska-Drużyńska, 2009). In the context of agriculture and water conservation, *hydrogels* have been shown to increase groundwater holding capacity, irrigation efficiency, and improve the physical and chemical properties of the soil (Suriadikusumah *et al.,* 2015; Zohuriaan-Mehr & Kabiri, 2008).

Characteristics of *Coffee Pulp* as a Biopore Filler

Coffee pulp (coffee husk) is a solid waste from coffee fruit processing that has a fairly high fiber content. The chemical content of *coffee pulp* includes cellulose (15–43%), hemicellulose, lignin, and nutrients such as nitrogen, phosphorus, and potassium (Puspitasari *et al.,* 2017). This structure makes *coffee pulp* have high natural porosity and has the potential to be a storage material and regulator of water movement in the soil. The application *of coffee pulp* in biopore systems has been tested in a coffee plantation in Bener Meriah, Aceh, and has been proven to loosen the soil, increase the volume of rainwater absorption, and accelerate the formation of natural compost (Aidilof *et al.,* 2023).

Previous Research

Various studies have been conducted related to the use of biopores and filler materials. Anggreni *et al.* (2023) evaluated the performance of biopore infiltration holes with variations of conventional organic filler media and concluded that the media has limitations in absorption capacity and decomposition speed. Hanuf *et al.* (2021) shows that *the Biopore Infiltration Hole* with Compost (BIHC) is able to increase the available water capacity by up to 65% on coffee plantations. Research on *hydrogels* by Sekizkardes *et al.* (2023) developing a polymerized *hydrogel* with strong mechanical properties and the ability to absorb water >2000 times its weight. However, research that combines *coffee pulp* and *hydrogel* as biopore fillers in *rain garden* systems is still very limited, so this research is important to fill this knowledge gap.

RESEARCH METHODS

This research is a quantitative research with an experimental approach. The location of the study is Jalan Baru Hamlet, Central Parsoburan District, Toba Regency, North Sumatra (Figure 1).

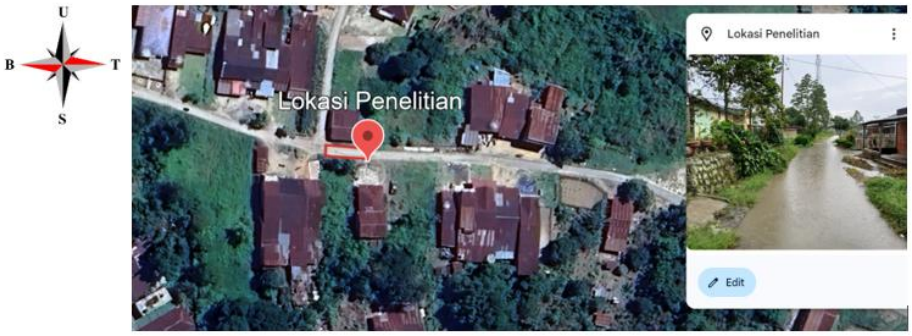


Figure 1. Research Location
Source: Researcher Documentation, 2026

Research Variables

1. Independent variables: Type of biopore filler media: (a) *Hydrogel* 100%, (b) *Coffee pulp* 100%, (c) Combination *of hydrogel–coffee pulp* with a ratio of 75%:25%, 50%:50%, and 25%:75%.
2. Bound variables: Water absorption rate (g/g/min) and water absorption capacity (g/g).
3. Control variables: Test water volume (800 g), container size, media sample weight (2 g).

Testing Procedure

The test will be carried out on January 02–05, 2026.
Testing procedure:

1. Weighing plastic containers.



Figure 2. Weighing Empty Containers
Source: Researcher Documentation, 2026

2. In container 1, weigh water ±800 g.



Figure 3. Weighing Water of ±800 g in Container 1
Source: Researcher Documentation, 2026

3. In container 2, weigh a total of 2 g of test media samples.



Figure 4. Weighing a Media Sample of ±2 g in Container 2
Source: Researcher Documentation, 2026

4. Pour water into container 2 and press the *stopwatch.*



Figure 5. Sample Immersion
Source: Researcher Documentation, 2026

5. Soak the sample at 5, 10, and 15 minutes.
6. Separating the water, weighing the wet weight of the sample (Wt).
7. Repeat three times for each variation, and the result is on average.

Data Analysis

The absorption rate (R) and absorption capacity (Q) are calculated by the formula:

$$R = \frac{(Wt - W0)}{W0 \times t} \quad \text{.....(Formula 1)}$$

$$Q = \frac{(Wt - W0)}{W0} \quad \text{.....(Formula 2)}$$

Description:

- (R) = water absorption rate (g/g/minute)
- (Q) = water absorption capacity (g/g)
- (W0) = initial weight of sample before immersion (g)
- (Wt) = Sample weight after immersion at a given time (g)
- (t) = immersion time (minutes)

The data was processed using Microsoft Excel and analyzed in a comparative descriptive manner.

RESULTS AND DISCUSSION

Hydrological Performance of Biopore Filler Media

The test results showed that each variation of the medium had significantly different hydrological characteristics (Graph 1 and Graph 2). The 100% hydrogel showed the highest performance with an average absorption rate of 40.34 g/g/min (5th minute) (Table 1) and an absorption capacity of 252.42 g/g (15th minute) (Table 2). This value confirms the properties of *superabsorbent polymer* (SAP) which is able to absorb water hundreds of times its dry weight through the osmotic swelling mechanism (Zohuriaan-Mehr & Kabiri, 2008). The decelerating absorption pattern is a typical characteristic of hydrophilic materials (Sannino *et al.,* 2009).

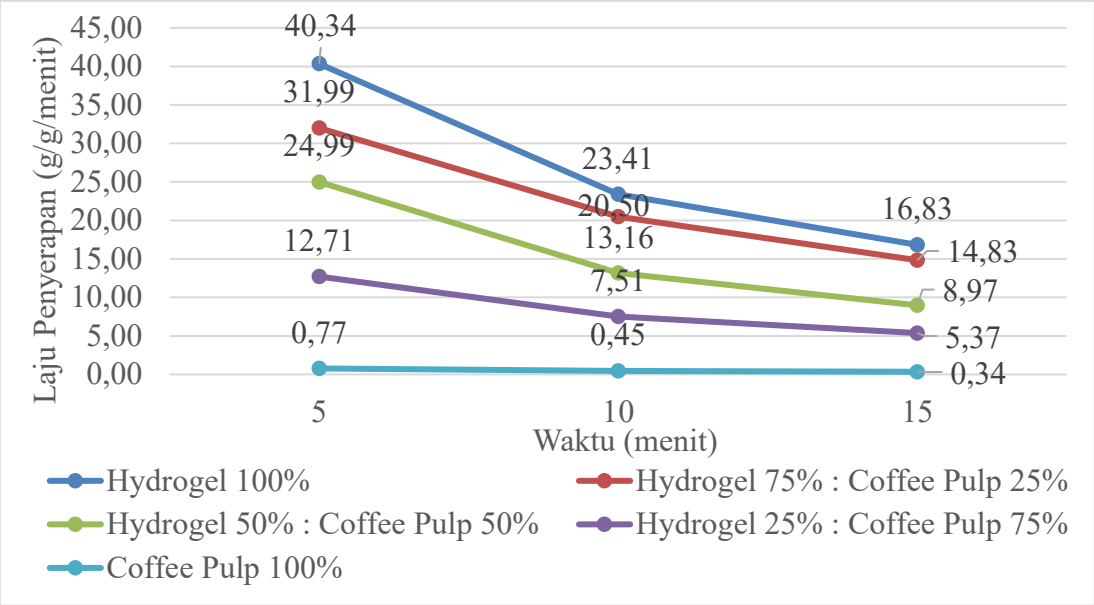
In contrast, *100% coffee pulp* has the lowest performance with an absorption rate of only 0.77 g/g/min (Table 1) and a capacity of 5.15 g/g (only about 2% of *hydrogels*) (Table 2). This low capacity is caused by an absorption mechanism dominated by capillarity and macroporous cavity filling, not *swelling* (Puspitasari *et al.,* 2017; Cervera-Mata *et al.,* 2022).

The *coffee pulp–hydrogel* combination shows the value between the two. In the *composition of 75% hydrogel*: *coffee pulp* 25%, absorption rate of 31.99 g/g/min (Table 1) and capacity of 222.50 g/g (Table 2). In a balanced composition of 50%:50%, the rate is 24.99 g/g/min (Table 1) and the capacity is 134.48 g/g (Table 2). At a composition of 25%:75%, the rate drops to 12.71 g/g/min (Table 1) and the capacity is 80.57 g/g (Table 2).

Table 1. Absorption Rate Test Results

Variase Media	Absorption Rate (g/g/min)		
	5'	10'	15'
100% Hydrogel	40,34	23,41	16,83
Hydrogel 75% : *Coffee Pulp* 25%	31,99	20,5	14,83
Hydrogel 50% : *Coffee Pulp* 50%	24,99	13,16	8,97
Hydrogel 25% : *Coffee Pulp* 75%	12,71	7,51	5,37
Coffee Pulp 100%	0,77	0,45	0,34

Source: Researcher Results, 2026

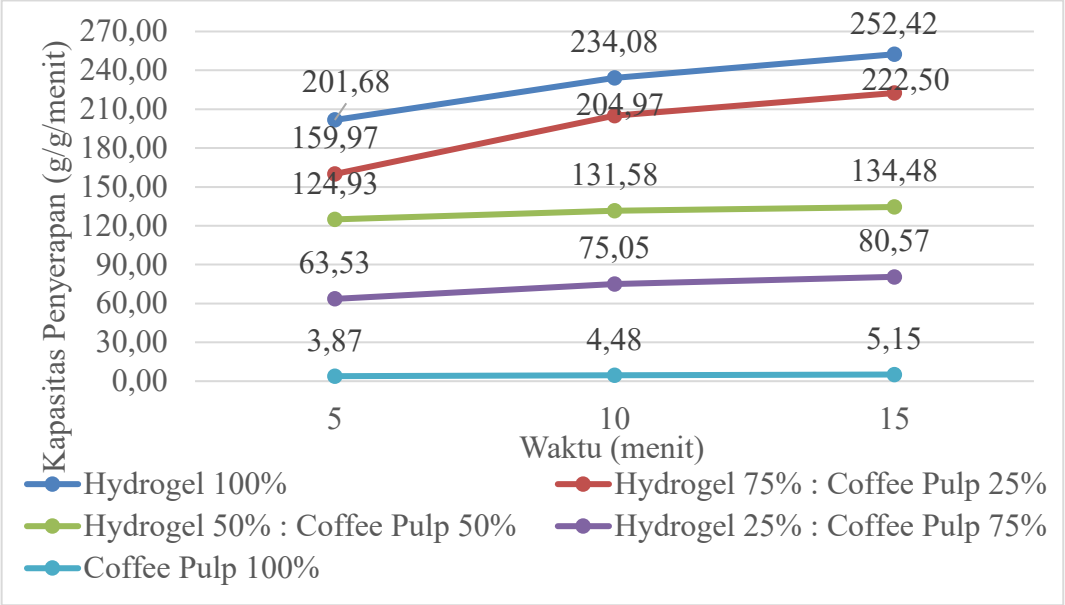


Graph 1. Absorption Rate Graph
Source: Researcher Results, 2026

Table 2. Absorption Capacity Test Results

Variase Media	Absorption Capacity (g/g)		
	5'	10'	15'
100% Hydrogel	201,68	234,08	252,42
Hydrogel 75% : *Coffee Pulp* 25%	160,00	204,97	222,5
Hydrogel 50% : *Coffee Pulp* 50%	124,93	131,58	134,48
Hydrogel 25% : *Coffee Pulp* 75%	63,53	75,05	80,57
Coffee Pulp 100%	3,87	4,48	5,15

Source: Researcher Results, 2026



Graph 2. Absorption Capacity Graph
Source: Researcher Results, 2026

Evaluation of the Optimal Media Combination

Quantitatively, 100% hydrogel has the highest hydrological capacity. However, for field applications, the combination of *50%* coffee pulp : *50% hydrogel* is the most optimal choice. This combination has an absorption capacity of 134.48 g/g (53% of pure *hydrogel*), exhibits a stable absorption pattern, and provides ecological benefits through the utilization of local coffee waste and long-term improvement of soil structure through the decomposition of organic matter. This is in line with the principles of the circular economy and supports the concept *of sustainable green infrastructure* (EPA, 2025).

Implications of Implementation in *Rain Garden Systems*

Rain gardens need a filler medium that is able to infiltrate water quickly to prevent stagnation, while also storing water to be released slowly. The combination of *50%* coffee pulp*: 50% hydrogel* is able to bridge these two functions. *Coffee pulp* provides porosity for initial infiltration, while *hydrogel* plays a role in water retention and gradual release. In addition, the presence of organic matter supports the activity of decomposer microorganisms that improve the soil structure around the biopore (Suriadikusumah et al., 2015). Thus, this system not only functions as a flood control infrastructure, but also as a microecosystem that supports soil health in a sustainable manner.

CONCLUSION

1. Experimental test results show that *the 100% hydrogel has the highest hydrological performance with an absorption rate of 40.34 g/g/min and a capacity of 252.42 g/g. 100% coffee pulp* has the lowest performance (rate of 0.77 g/g/min; capacity of 5.15 g/g). The *coffee pulp–hydrogel* combination shows a value between the two with a proportional tendency to hydrogel content;
2. Based on performance comparisons and ecological considerations, the combination *of 50%* coffee pulp : *50% hydrogel* is the most optimal choice for application as a biopore filler. This combination has an absorption capacity of 134.48 g/g, a stable absorption pattern, and provides additional benefits in the form of local waste utilization and long-term soil structure improvement.

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