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Performance of infiltration wells in commercial building along the Kaliurang Road, Yogyakarta, between km 12 – 13 in 2017

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Abstract

Previous studies have shown that incorporating infiltration wells into drainage systems can significantly reduce surface runoff. However, the actual effectiveness of these wells in absorbing rainfall remains uncertain. This article evaluates the performance of infiltration wells installed at commercial buildings along Kaliurang Road (km 12–13) in 2017. Precipitation data was collected from the nearest weather stations: Kemput, Beran, and Bronggang. The design of the infiltration wells followed the Sunjoto technique, utilizing rainfall data from 2001 to 2020 to determine the rainfall intensity for a 5-year return period. To assess the wells' efficiency, daily rainfall data was converted to hourly data using Tadashi Tanimoto's method. The flow rate from rainfall on the roof was compared with the capacity of the infiltration wells. In 2017, the wells' capacity exceeded the flow rate on 363 out of 365 days, demonstrating an exceptionally high-performance rate of 99.45%. On September 28 and November 28, 2017, however, the wells were unable to handle the rainfall due to insufficient capacity.

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Introduction

Background

The northern part of Yogyakarta, particularly along Kaliurang Road where the Integrated Islamic University of Indonesia campus is located, has become a prime area for the development of commercial buildings, including student residences. This development has led to an increase in impermeable surfaces and a higher demand for water. Situated on the slopes of Mount Merapi, this region benefits from substantial groundwater reserves. Consequently, many residences rely heavily on groundwater, as it is more cost-effective than using water from the local water supply company, PDAM.

However, the imbalance between groundwater extraction and natural replenishment has resulted in a declining free groundwater level. While the effects may not be immediately noticeable, they pose long-term risks. Therefore, groundwater conservation efforts are essential.

One effective conservation measure is the construction of infiltration wells. These wells capture rainwater that falls on roofs and other impermeable surfaces, allowing it to be absorbed into the ground and replenishing groundwater reserves (Baskoro, 2022). Additionally, infiltration wells help reduce surface runoff, which can decrease the risk of flooding and related disruptions (Bahunta, 2019). Yadaf, Manisha, and Setia (2016) also emphasize that infiltration wells contribute to reducing surface flooding and enhancing aquifer reserves.

Despite these benefits, the actual performance of infiltration wells in handling real rainfall remains uncertain. This study aims to evaluate the performance of infiltration wells installed in commercial buildings along Kaliurang Road (km 12–13) in Yogyakarta, specifically assessing their effectiveness in managing actual rainfall.

Previous research

Several studies have explored drainage systems from an environmental perspective, specifically focusing on the role of rainwater infiltration wells. Notable examples include Study of Surface Runoff Management Using Infiltration Wells (Saleh, 2011) in the Made National Housing Area, Lamongan Regency, and Reduction of Drainage Channel Dimensions Due to the Existence of Infiltration Wells in the Maguwoharjo – Wedomartani Drainage Network, Sleman, Yogyakarta (Purnomo, 2013). Additionally, research such as Comparison of SNI 03-24533-2002 and Sunjoto Methods in the Design of Infiltration Wells for Commercial Buildings on Kaliurang Road, Yogyakarta (Ramadhani, 2016) and Comparison of Drainage Channel Dimensions with or Without Infiltration Wells in the Indonesian Islamic University Area (Wijaya, 2019) has contributed to our understanding of drainage design. More recently, Performance of Integrated Campus Infiltration Wells from 2007 to 2016 (Astuti, 2020) examined long-term infiltration well performance on a university campus.

These studies primarily focus on the function of infiltration wells in reducing surface runoff and conserving groundwater. However, there is limited research that evaluates the response or performance of infiltration wells when subjected to actual rainfall events.

Groundwater

Definition

According to Purnama (2010), groundwater refers to water located beneath the earth's surface in a zone where the soil or rock is fully saturated with water, and the pressure of this water is equal to or greater than atmospheric pressure. The primary source of groundwater is rainwater that infiltrates the soil through a process known as the hydrological cycle. The availability of groundwater varies by region, with some areas having abundant groundwater resources while others may have limited groundwater potential due to factors such as geographical location, soil composition, and rainfall distribution.

Groundwater Flow System

The path groundwater follows to its discharge point is known as the flow path. When multiple flow paths exist with balanced recharge and discharge areas, they form what is called a groundwater flow system. A three-dimensional closed system that contains all the flow paths within a groundwater system is referred to as a groundwater basin.

Groundwater possesses energy primarily due to its elevation (gravity height) and pressure (pressure height). While groundwater can also have kinetic energy from its movement, this energy is typically negligible due to the low velocity of groundwater flow. Groundwater naturally moves from areas of higher energy to areas of lower energy. The energy of groundwater is measured by the level at which water stands in a borehole drilled into an aquifer, relative to a reference point, such as sea level. This measurement is known as the hydraulic head, or simply the head. For practical purposes, hydraulic head is the sum of pressure head and elevation head, both representing forms of potential energy.

The change in hydraulic head over a specific distance along a groundwater flow path is referred to as the hydraulic gradient, which drives groundwater movement. According to Darcy's law, which describes groundwater flow through an aquifer, the flow rate is directly proportional to the cross-sectional area through which it passes and the hydraulic gradient. Gravity, due to differences in elevation, is the primary force driving groundwater movement. Under natural conditions, groundwater flows “downhill” until it emerges at the surface, such as in springs, or enters the root zone where it can evaporate or be taken up by plants.

Therefore, groundwater generally moves from higher elevation areas between streams (interstream) toward lower elevations, such as rivers or coastal areas. Despite minor surface irregularities, the overall slope of the land directs groundwater toward rivers or beaches. Groundwater levels tend to be deeper between rivers and closer to the surface in floodplain areas, with the water table often mimicking the shape of the land's surface (Sophocleous, 2005).

Groundwater flow patterns are influenced by the shape of the water table and the distribution of hydraulic conductivity in the underlying rocks. The water table itself is shaped by the topography and the local climate. As a result, groundwater flow is a function of topography, geology, and climate, collectively referred to as the hydrogeological environment. Additionally, biotic factors, such as vegetation, play a role in controlling the rate of evapotranspiration, while human activities are continuously altering the distribution and behavior of water on land.

Infiltration

Infiltration refers to the process by which rainwater and other surface water permeates the ground, passing through the soil surface into the groundwater layers. This process is a critical component of the hydrological cycle and significantly influences groundwater availability in a given area.

Infiltration is typically characterized in two dimensions: infiltration capacity and infiltration rate. The infiltration rate is the actual speed at which water enters the soil, while infiltration capacity represents the maximum rate at which infiltration can occur. Infiltration capacity is generally higher at the onset of a heavy rain event, but as the rain continues, the rate decreases and eventually stabilizes at a constant infiltration rate.

Permeability

Permeability refers to the characteristic of a material, soil, or rock that allows liquids to flow through its pores. It is typically quantified by the rate at which liquid passes through the material. The permeability value can often be equated with the constant infiltration rate, but it can also be determined through other field measurement methods, such as using a tracer material and two test wells for observation Purnama (2010).

Groundwater recharge

To address groundwater deficits, several methods of artificial recharge have been proposed, such as creating artificial ponds fed by river water (Todd, 1980 in Suripin, 2004), constructing pools around homes (Seaburn, 1970 in Suripin, 2004), utilizing porous drainage net pipes for rainwater absorption (Dune and Leopold, 1978 in Suripin, 2004), and spreading water over large land areas to irrigate agricultural fields.

Artificial groundwater recharge offers several benefits:

1. Storing surplus surface water in underground reservoirs.
2. Enhancing the quality of local groundwater by mixing it with replenished rainwater.
3. Creating a pressure barrier to prevent saltwater intrusion.
4. Increasing groundwater availability for drinking and other uses.
5. Reducing pump operating costs as groundwater levels rise.
6. Preventing the lowering of groundwater levels, which can lead to land subsidence.

Certain physical criteria must be met for successful artificial groundwater recharge:

1. Adequate storage capacity. Locations with shallow groundwater tables or high piezometric pressure are unsuitable.
2. Availability of sufficient water with a quality that is better than the local groundwater.
3. Soil or rock at the site must have sufficient transmissibility or permeability for water movement.

Infiltration Well

Sunjoto (2015) proposed a formula for planning the depth of an infiltration well. Rain that falls on the roof of the building is channeled into the infiltration well. The flow mechanism is unsteady flow.

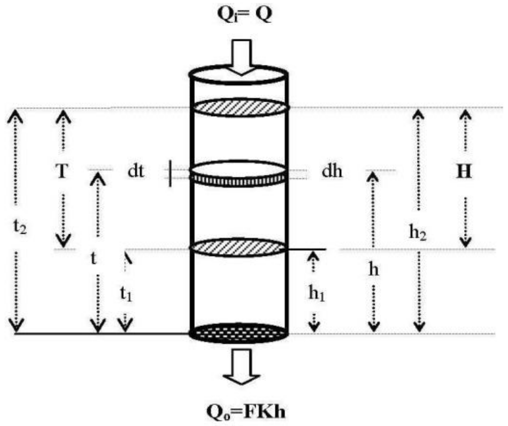

Figure 1. Unsteady flow approach to infiltration wells

Q_i is the flow rate due to rain falling on the roof of the building = Q
Q_0 is the flow rate that seeps into the ground = F.K.h
There is equation:
Volume of water in the well = $(Q_i - Q_0)$. dt
So the following equation will be obtained.

$$H = \frac{Q}{F.K}\left(1 - e^{-\frac{F.K.T}{\pi.R^2}}\right) \qquad (1)$$

Where H is the depth of the well (m), Q is the flow rate due to rain falling on the roof of the building (m^3/s), F is the geometric factor or shape factor (m), K is the soil permeability coefficient (m/s), T is td, duration of dominant rain (s), R is the radius of the infiltration well (m).

Duration of dominant rain (td) is the most frequent rainfall period in the area.

Geometric factors, or shape factors, significantly impact the performance of infiltration wells. These factors include the shape of the well, the radius, the thickness of the well walls, and the well's position relative to the soil layers. Additionally, the surface area of the land serving as the infiltration medium contributes to the geometric factor, denoted as F. In this study, the planned infiltration well is situated in porous soil, with watertight walls and a permeable flat bottom. This configuration allows efficient water infiltration, as depicted in Figure 2, illustrating the design of the infiltration well.

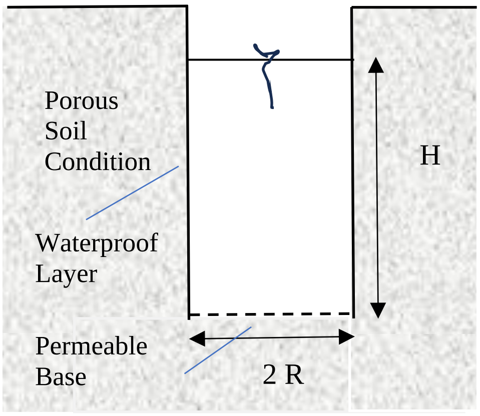

Figure 2. Sketch of well condition ($F = 2\pi R$)

The geometric factor value in this condition can be formulated as follows.

$$F = 2\pi R \qquad (2)$$

with F = geometric factor (m) and R = well radius (m).

The soil permeability coefficient is a measure of the soil's capacity to allow the passage of liquids, typically water, through its pore spaces. It is commonly expressed as the rate at which liquid flows through materials such as soil and rocks. This coefficient can be determined through field measurements using tracer substances and observation wells, or alternatively, it can be equated to the constant infiltration rate of the soil (Purnama, 2010).

Infiltration wells serve two critical functions:

1. Reduction of surface runoff, which helps manage excess water and prevent flooding in developed areas.
2. Groundwater conservation, as they allow rainwater to percolate into the ground, replenishing underground water reserves.

To design a system of infiltration wells, both the available land and the capacity of each well must be taken into account. The capacity of a single well can be calculated using a specific formula (Astuti, 2020), which takes into consideration factors such as soil permeability, well dimensions, and the infiltration rate. This formula, denoted as Eq. (1), is applied to determine the capacity of the planned wells and subsequently the number of wells required for optimal performance in reducing runoff and promoting groundwater recharge.

$$Q_{1well} = \frac{F.K.H_{1\,well}}{1-e^{-\frac{F.K.T}{\pi.R^2}}} \tag{3}$$

$$n_{well} = \frac{Q}{Q_{1\,well}} \tag{4}$$

The choice of well diameter should ideally be adjusted to the land area and the aesthetics desired by the land owner. (Rahmadi, 2021)

Maintenance

For infiltration wells to remain effective, proper maintenance is essential. This includes regularly cleaning the water pipes and removing any dust or debris that has accumulated in the filtering material, such as fiber, within the well. By ensuring that these components are kept clean, the infiltration well can maintain maximum flow velocity as water enters the ground, particularly during the rainy season, when its performance is most critical (Tiwery, 2020). Regular maintenance ensures that the infiltration process is efficient, preventing blockages that could reduce the well's capacity to recharge groundwater.

Methodologi

This research does not focus on the design of infiltration wells, as the wells already exist. Instead, it evaluates and analyzes the performance or response of these infiltration wells to actual rainfall events that occurred in 2017.

The research begins with a comprehensive literature review, including references from books and previous studies on infiltration wells found in journals or proceedings. Based on this review, the research title is formulated. After that, the background and objectives of the study are clearly written, setting the foundation for assessing the real-world effectiveness of infiltration wells in managing surface runoff and replenishing groundwater reserves.

The next stage of the research involves collecting the following data:

1. 2017 rainfall data from Beran Station, Bronggang Station, and Kemput Station.
2. Roof area data at the research location to calculate the total surface area contributing to runoff.
3. Data on the number of infiltration wells to assess how many are in place for managing the runoff.
4. Soil permeability coefficient data to understand the rate at which water can infiltrate through the soil.
5. Design rainfall for a 5-year return period, derived from rainfall data spanning from 2001 to 2020.

The performance of the infiltration wells is calculated by the percentage of wells absorbing flow discharge from rain on the roof during 2017. This is then discussed in relation to theory and prior research, followed by conclusions and suggestions.

The research location is on Jl Kaliurang km 12 – 13 Yogyakarta, focusing on commercial buildings or rented boarding houses.

Analysis Data

The commercial buildings cover 14 locations. With data as shown in Table 1 below.

Table 1. Commercial building data

Commercial building	Roof Area (m^2)	Permeability Coef. (m/s)
1	239,4	0,000017
2	192,8	0,0000033
3	431,8	0,000033
4	145,7	0,0000267
5	460,1	0,0000267
6	401,1	0,0000267
7	383,8	0,0000267
8	565,2	0,0000267
9	182	0,0001267
10	226,2	0,0000733
11	247,9	0,00003
12	208	0,0000367
13	411,2	0,0000567
14	162,1	0,00004

Based on previous research by Ramadhani (2016), the infiltration well data for each commercial building location is presented. The infiltration wells have a diameter of 1 meter and a depth of 2.5 meters, with a well shape factor of 2πR, approximately 3.1416 meters. The design rainfall for a 5-year return period is 117.8 mm, and the rain intensity, calculated using the Mononobe formula for the same return period, is 25.73 mm/hour. The infiltration well design is based on the Sunjoto method, which considers these parameters to estimate the infiltration capacity.

Table 2. Number of infiltration well

Commercial Building	n	$Q_{1\text{ well}}$ (m^3/s)	Q well (m^3/s)
1	4	0,000345	0,001380
2	4	0,000286	0,001143
3	6	0,000423	0,002535
4	2	0,000391	0,000782
5	7	0,000391	0,002736
6	6	0,000391	0,002345
7	6	0,000391	0,002345
8	8	0,000391	0,003127
9	1	0,001022	0,001022
10	2	0,000655	0,001310
11	4	0,000407	0,001629
12	3	0,000442	0,001325
13	4	0,000553	0,002214
14	2	0,000459	0,000919

The area rainfall analysis is conducted using the algebraic average of the three closest stations: Beran station, Bronggang station, and Kemput station. The rain intensity for any given day follows the distribution of rainfall over time, according to Tadashi Tanimoto's method (Triatmojo, 2013). The results of these calculations for area rainfall are shown in Table 3 below.

Table 3. Area rainfall on November 2017

Date	Beran (mm)	Bronggang (mm)	Kemput (mm)	Area Rainfall (mm)
Nov 1	0	0.0	0.0	0.00
Nov 2	0	0.5	0.0	0.17
Nov 3	0	0.0	0.0	0.00
Nov 4	40	13.0	127.0	60.00
Nov 5	44	17.0	36.0	32.33
Nov 6	22	5.0	0.0	9.00
Nov 7	0	0.0	0.0	0.00
Nov 8	0	7.0	0.0.	2.33
Nov 9	30	5.0	30.0	21.67
Nov 10	21	0.0	0.0	7.00
Nov 11	10	6.0	21.0	12.33
Nov 12	9	45.0	0.0	18.00
Nov 13	35	17.0	0.0	17.33
Nov 14	0	7.0	58.0	21.67
Nov 15	2	0.0	0.0	0.67
Nov 16	26	18.0	115.0	53.00

Table 3 (continued). Area rainfall on November 2017

Date	Beran (mm)	Bronggang (mm)	Kemput (mm)	Area Rainfall (mm)
Nov 17	153	7.5	19.0	81.50
Nov 18	71	6.5	29.0	35.50
Nov 19	32	9.3	0.0	13.77
Nov 20	28	5.0	76.0	36.33
Nov 21	0	45.3	0.0	15.10
Nov 22	4	0.0	0.0	1.33
Nov 23	13	13.0	0.0	8.67
Nov 24	19	11.0	10.0	13.33
Nov 25	32	0.0	0.0	10.67
Nov 26	23	17.5	28.0	22.83
Nov 27	37	13.0	15.0	21.67
Nov 28	228	133.0	117.0	159.33
Nov 29	67	36.5	18.0	40.50
Nov 30	7	3.0	0.0	3.33

For analysis of rain intensity, Tadashi Tanimoto's hourly rain distribution method was used at hour 1. An example on 28 November 2017 can be seen in Table 4 below.

Table 4. Tadashi Tanimoto's method hourly rainfall distribution on Nov 28 2017

Date	Area rainfall (mm)	Hour to	Rainfall (mm)	Rainfall Intensity (mm/hr)
Nov 28	159,33	1 (26%)	41,43	41,43
		2 (24%)	38,24	
		3 (17%)	27,09	
		4 (13%)	20,71	
		5 (7%)	11,15	
		6 (5,5%)	8,76	
		7 (4%)	6,37	
		8 (3,5%)	5,58	

Results and Discussion

Results

The runoff discharge due to rain falling on the roof of each commercial building location is shown in Table 5 below, using a roof surface run off coefficient (C) of 0.75.

Table 5. Runoff discharge due to rain falling on the roof (Q roof) as an example on November 28, 2017

Commercial Building	I (mm/hour)	Roof Area (m^2)	Q roof (m^3/s)
1	41,43	239,4	0,00207
2	41,43	192,8	0,00166
3	41,43	431,8	0,00373
4	41,43	145,7	0,00126
5	41,43	460,1	0,00397

Table 5 (continued). Runoff discharge due to rain falling on the roof (Q roof) as an example on November 28, 2017

Commercial Building	I (mm/hour)	Roof Area (m^2)	Q roof (m^3/s)
6	41,43	401,1	0,00346
7	41,43	383,8	0,00331
8	41,43	565,2	0,00488
9	41,43	182	0,00157
10	41,43	226,2	0,00195
11	41,43	247,9	0,00214
12	41,43	208	0,00180
13	41,43	411,2	0,00355
14	41,43	162,1	0,00140

Furthermore, Q roof and Q infiltration wells are compared, every day in 2017. If Q infiltration well > Q roof, then the performance of the infiltration well is 100%. If Q infiltration well < Q roof, then the performance is 0%. The performance of infiltration wells every day of the year can be seen in Table 6 below. Because 365 days is too many, the dates 1 November 2017 to 30 November 2017 were taken as an example at location 1.

Table 6. Performance of infiltration wells at location 1, November 2017

Date	Qwell (m^3/s)	Qroof (m^3/s)	Performance Infiltration Well
Nov 1	0,00138	0.000000	100%
Nov 2	0,00138	0,000002	100%
Nov 3	0,00138	0.000000	100%
Nov 4	0,00138	0,000778	100%
Nov 5	0,00138	0,000420	100%
Nov 6	0,00138	0,000117	100%
Nov 7	0,00138	0.000000	100%

Table 6 (continued). Performance of infiltration wells at location 1, November 2017

Date	Qwell (m^3/s)	Qroof (m^3/s)	Performance Infiltration Well
Nov 8	0,00138	0,000030	100%
Nov 9	0,00138	0,000280	100%
Nov 10	0,00138	0,000091	100%
Nov 11	0,00138	0,000160	100%
Nov 12	0,00138	0,000233	100%
Nov 13	0,00138	0,000225	100%
Nov 14	0,00138	0,000281	100%
Nov 15	0,00138	0,000009	100%
Nov 16	0,00138	0,000687	100%
Nov 17	0,00138	0,001057	100%
Nov 18	0,00138	0,000460	100%
Nov 19	0,00138	0,000179	100%
Nov 20	0,00138	0,000471	100%
Nov 21	0,00138	0,000196	100%
Nov 22	0,00138	0,000017	100%
Nov 23	0,00138	0,000124	100%
Nov 24	0,00138	0,000173	100%
Nov 25	0,00138	0,000138	100%
Nov 26	0,00138	0,000296	100%
Nov 27	0,00138	0,000281	100%
Nov 28	0,00138	0,002066	0%
Nov 29	0,00138	0,000525	100%
Nov 30	0,00138	0,000043	100%

Then calculate how many days in 2017 Q infiltration wells > Q roof. At all locations only on 28 September and 28 November 2017, Q infiltration wells < Q roof. This means that the performance of infiltration wells in 2017 is 363/365 x 100%=99.45%.

Discussion

The performance of infiltration wells in 2017 was very high, namely 99.45%, almost 100%. There were only 2 days, namely on September 28 and November 28, where Q infiltration wells < Q roof.

The Sunjoto method of infiltration well design using the Mononobe formula rain intensity with a return period of 5 years is appropriate, it can produce 99.45% performance. If you use a higher reset time, it will be wasteful. So, it is appropriate to design infiltration wells using rainfall intensity over a 5 year return period.

The conditions for land that can be built for infiltration wells are that it has a shallow groundwater level that is deep enough (minimum 1.5 m in the rainy season), has sufficient distance from buildings, has a soil permeability of > 2 cm/hour or 0.0000056 m/ s. Almost all commercial building locations have a permeability coefficient of > 2 cm/hour, meaning it is feasible to build infiltration wells. Only location 2 has a permeability coefficient (K) < 2 cm/hour.

To determine the number of infiltration wells needed, it should not be calculated from the total depth divided by the depth of 1 well, because the approach is unsteady flow. However, what is correct is that it is calculated from the total runoff discharge from the roof that enters the well divided by the capacity of 1 well.

Poor surface water quality can be overcome naturally through acid and alkali processing (karst rocks) and turbidity cleaning with sand layer filters (Tjahjanto, D, 2008).

Conclusion

From the description above, it can be concluded that:

1. The performance of infiltration wells in 2017 was very good, approaching 100%, namely 99.45%. There are only 2 days, namely September 28 and November 28, 2017, where Q infiltration well < Q roof.
2. The Sunjoto method of infiltration well design using the Mononobe formula rain intensity with a return period of 5 years is appropriate, it can produce 99.45% performance.

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