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Infiltration Wells Effectiveness Analysis: Study in Purwantoro Village, Malang City

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Abstract: Infiltration wells are one of the effective infrastructure in draining rainwater so that they can reduce waterlogging, but existing infiltration wells need to be reviewed for their effectiveness as water shortages are still occurring especially in the Purwantoro Village.The study aims to determine the effectiveness of Infiltration wells and calculate the appropriate number of infiltration wells in Purwantoro Village. The method used in this research is a hydrological analysis, planned flood discharge analysis dan infiltration well effectiveness analysis. The results of the study showed that the effectiveness of existing infiltration wells in Purwantoro Village varies greatly, with the highest at 82.8% and the lowest at 11.3%. To increase the effectiveness of infiltration wells, as many as 109 infiltration wells are needed in Purwantoro Village to reduce waterlogging. The conclusion of this study is the lack of effectiveness of infiltration wells in Purwantoro Village because the number of infiltration wells is still limited, so it is necessary to add infiltration wells and maintenance of infiltration wells is needed to reduce deposits contained in infiltration wells.

Keywords: Effectiveness; Flood discharge; Infiltration wells

Introduction

Malang City is located in the Brantas Ground Water Basin (CAT) and is crossed by the Brantas River with several tributaries, namely the Metro River, Sukun River, Bango River, and Amprong River (Pemerintah Kota Malang, 2023). It is these topographical and hydrological conditions that cause frequent flooding disasters in Malang City. Based on Malang City's data in the 2023 Census, Blimbing District is the district with the highest number of flood incidents from 2019 to 2021 compared to other districts in Malang City. One of the villages in Blimbing District with a high level of flood risk is Purwantoro village (Ramadhani et al., 2022). Purwantoro Village is not exempt from the development that continues to occur every year, which further reduces the area of water infiltration. In addition, the drainage channel in Purwantoro Village is still not able to accommodate the discharge for a period of 5 years with a maximum dam height of 0.7 meters (Kinanthi et al., 2023). Poor drainage systems, damming, and climate change contribute to flooding. Therefore, it is necessary to design sustainable flood control approaches (Oriaifo et al., 2020). Poor drainage systems and drainage capacity that cannot hold rainwater are one of the causes of flooding (Aurdin, 2019; Ikhwanudin et al., 2020; Siregar et al., 2023).

Flooding is a global problem that occurs in various countries (Cornwall, 2021; Ganot et al., 2017; Hu et al., 2021; Purwanto et al., 2023). Urban flooding is usually an annual event, which increases the potential for flood damage due to climate change and urbanization and cannot be underestimated (Moon et al., 2024; Petroselli et al., 2020; Tariq et al., 2023; Wang et al., 2024). Floods cause various losses, including in the monetary and demographic, social and economic, and educational fields (Kang et al., 2021; Purwanto et al., 2023; Sayama et al., 2015). One of the most effective efforts to overcome

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flooding and congestion is the construction of infiltration wells that are evenly spaced in areas prone to urban waterlogging (Jifa et al., 2018; Vanegas-Espinoza et al., 2022).

Table 1. Location of the Purwantoro Village Infiltration Wells

Location of infiltration wells	Total
Jl. Indragiri V Rt 2 Rw 1	2
Jl. Genuk Watu Barat Rt 1 Rw 3	2
Jl. Letjen S. Parman I Rt 5 Rw 5	7
Jl. Karya Timur I Rt 5 Rw 7	1
Jl. Simpang Aluminium Rt 5 Rw 9	1
Jl. Letjen S. Parman III Rt 1 Rw 18	2
Jl. Letjen S. Parman IV Rw 23	23
Jl. Taman Indragiri Rt 3 Rw 1	1
Jl. Industri Timur Rt 1 Rw 2	1
Jl. Sulfat Agung Rw 21	2
Total	42

The volume and efficiency of a well can be calculated based on the balance of water entering the well and water absorbing into the soil. The efficiency of the infiltration wells is the percentage of the drain discharge without infiltration wells with the draining debit with infiltration wells, indicating the degree of efficiency in the construction of infiltration wells in an area (Suripin, 2003). Infiltration wells can be said to be effective if there are changes in the discharge flow to existing drainages. This happens because the discharge that flows into the existing drainage enters the infiltration wells. Flood discharge values are reduced after using infiltration wells, with the type of infiltration well that has the greatest effectiveness in mitigating drain is a well that is high water in a drained well equal to the high drain capacity of the well and the soil surface around the infiltration well is not watertight (Rina et al., 2018). Meanwhile, the potential effectiveness of infiltration wells above 50% can be used as a reference for efforts to reduce flood risk (Pamungkas et al., 2022) and reducing the top of the flood using infiltration wells has an efficiency of up to 50% compared to without wells (Kusumastuti et al., 2017).

Infiltration wells are used to harvest rainwater to reduce the risk of flooding (Netzer et al., 2024). Fallen rainwater is drained into the infiltration wells through water channels to reduce the amount of surface water runoff (Muntaha et al., 2022). Infrastructure development, in this case a sewerage well, should be able to provide benefits to the community if implemented by a defined policy, but if it is not appropriate it will have an impact on the environmental balance (Tarigan et al., 2014). Infiltration wells are estimated to be able to reduce 10% -15% of surface runoff in Lowokwaru District, Malang City, especially around Jalan Soekarno-Hatta, which is the location of waterlogging, especially during the rainy season. Infiltration wells are proposed as a solution for reducing waterlogging due to their efficiency (Hirijanto et al., 2021).

Previous infiltration wells research focused on calculating the effectiveness of infiltration wells in reducing water runoff (Dewa et al., 2021; Mulyono et al., 2021; Rina et al., 2018), the existence of infiltration wells can reduce surface runoff that causes flooding. Another study calculated the number of infiltration wells needed in an area, such as in Lowokwaru sub-district, Malang City, as many as 272 infiltration wells (Hirijanto et al., 2021), in Babakan village, Bogor Regency as many as 115 pieces (Bahunta et al., 2019), and in PU Polytechnic as many as 554 infiltration wells (Herwindo et al., 2023). This study in addition to calculating the effectiveness of infiltration wells also calculates the infiltration well plan needed in each research area in Purwantoro Village, which is divided into 10 research areas.

Method

This study was conducted in Purwantoro Village, Blimbing District, Malang City. The area of the village is 2.2925 km2 and has a population density of 11,122 people per km^2. The infiltration wells sampling technique in this study is a purposive sampling technique. 10 infiltration wells were selected purposively for this study based on the level of inundation vulnerability. The locations of infiltration well samples are Jalan Indragiri, Jalan Genuk Watu Barat, Jalan Letjen S. Parman I, Jalan Letjen S. Parman III, Jalan Letjen S. Parman IV, Jalan Karya Timur, Jalan Simpang Aluminium, Jalan Taman Indragiri, Jalan Industri Timur and Jalan Sulfat Agung. The data used in this study are primary data and secondary data. Primary data collection is carried out through field observations to obtain data on soil permeability and existing conditions of infiltration wells. Meanwhile, secondary data is obtained through the Regional Development Planning Agency and Purwantoro Village.

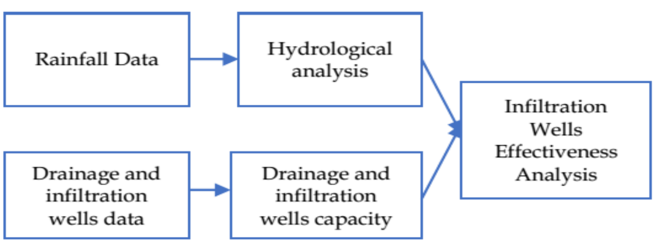

Figure 1. Analytical framework

The analysis used to calculate the effectiveness of infiltration wells is hydrological analysis, design flood discharge analysis and infiltration wells effectiveness analysis. In hydrological analysis, rain data consistency tests are used using the RAPS (Rescaled Adjusted Partial Sums) method. The consistency of rainfall data needs to be tested, avoid data errors, and be able to present data on real conditions at the study site (Ghaisani et al., 2024). Rescaled Adjusted Partial Sums (RAPS) is a commonly used consistency test method, according to previous research (Đurin et al., 2023; Suhartanto et al., 2021).

Frequency analysis of rainfall data is a method used to predict planned rainfall for a certain repeat period (Aurdin, 2019; Ghaisani et al., 2024; Ginting et al., 2017). There are several distribution functions used, including normal, normal log, Gumbel, and Pearson III log. In this study, frequency analysis of rainfall data used the gumble distribution and the pearson III log distribution. While data alignment tests using the Smirnov Kolmogorov method and chi square method (Kinanthi et al., 2023). In the design flood discharge analysis, the area of water catchment is calculated, the capacity of drainage channels and soil permeability are used to determine the speed of water absorption in the soil.

The effectiveness of infiltration wells is a percentage figure between runoff discharge without infiltration wells and runoff discharge with infiltration wells which shows the level of effectiveness of infiltration well development in an area. Infiltration wells can be said to be effective if there are changes in the discharge flowing into the existing drainage. This happens because the discharge flowing into the existing drainage enters the infiltration wells (Susilo et al., 2016).

Result and Discussion

Hydrological Analysis

The hydrological analysis carried out included a consistency test of rainfall data, a frequency analysis of precipitation data, and a test of data alignment.

Rain data consistency test

Table 2. Rain Data Consistency Test

Consistency 90%						
$Q/n^{0.5}$	=	0.54	<	1.05	→	Eligible
$R/n^{0.5}$	=	1.14	<	1.20	→	Eligible
Consistency 95%						
$Q/n^{0.5}$	=	0.54	<	1.14	→	Eligible
$R/n^{0.5}$	=	1.14	<	1.28	→	Eligible
Consistency 99%						
$Q/n^{0.5}$	=	0.54	<	1.29	→	Eligible
$R/n^{0.5}$	=	1.14	<	1.28	→	Eligible

The Rescaled Adjusted Partial Sums (RAPS) method is used to test the consistency of rainfall data. The test is considered eligible if the statistical test result $Q_{RAPS}/\sqrt{n}$ is smaller than the critical value of the appropriate confidence level.

Based on the results of the above calculations, it was concluded that $Q_{RAPS}/n^{0.5}$ is smaller than the critical value of the appropriate confidence level so that the rainfall data used is eligible for further testing.

Rainfall Frequency Data Analysis

The methods used are the Gumbel distribution and the Log Pearson III distribution. From Table 3, the Gumbel and log Pearson III distribution values can be seen based on return periods of 2 years to 1000 years.

Table 3. Rainfall Frequency Data Analysis

Tr	Distribution Gumbel	Distribution Log Pearson III
2	100.08	103.46
5	125.84	121.91
10	142.89	131.04
20	159.26	137.07
25	164.45	140.21
50	180.44	145.76
100	196.31	150.46
200	212.12	154.52
1000	248.75	162.05

Data Alignment Test

The alignment of rainfall data was tested using the Smirnov-Kolmogorov Test and Chi-Square Test methods.

Table 4. Recapitulation Results

$D_{critical}$	D_{max}	Conclusion	Description
0.41	0.16	$D_{max} < D_{critical}$	Gumbell Hypothesis Accepted
0.49	0.16	$D_{max} < D_{critical}$	Gumbell Hypothesis Accepted
0.41	0.13	$D_{max} < D_{critical}$	Log Pearson III Hypothesis Accepted
0.49	0.13	$D_{max} < D_{critical}$	Log Pearson III Hypothesis Accepted

Based on the results of the Smirnov-Kolmogorov test, it is known that the Gumbel hypothesis and Log Pearson III hypothesis can be accepted because the value $D_{max} < D_{critical}$.

Table 5. Recapitulation Results of Chi-Square Gumbel Distribution and Log Pearson III Distribution Test

	Gumbel		Log Pearson III	
Significant (%)	5%	1%	5%	1%
$X^2_{critical}$	5.99	9.21	5.99	9.21
$X^2_{calculation}$	3.60	3.60	5.20	5.20
Conclusion	Accepted	Accepted	Accepted	Accepted

Based on Table 5, it can be concluded that data alignment tests using the Smirnov-Kolmogorov and Chi-Square methods are acceptable.

Infiltration Wells Effectiveness Analysis

Analysis of Drainage Channel Capacity

In analyzing drainage channel capacity, the data required includes channel dimensions, channel length, channel wall roughness coefficient, elevation, and slope. Then calculate the wet cross-sectional area of the channel (A), wet channel perimeter (P), hydraulic radius (R), flow velocity (V), and flow discharge (Q_{sal}).

Table 6. Drainage Channel Capacity

Location	A (m^2)	P (m)	R (m)	V (m/s)	Q_{drain} (m^3/s)
Indragiri V	0.09	0.90	0.10	0.13	0.01
Genuk Watu Barat	0.09	0.90	0.10	0.21	0.02
Letjen S. Parman I	0.26	1.70	0.15	0.37	0.10
Karya Timur I	0.15	1.10	0.14	0.26	0.04
Simpang Aluminium	0.09	0.90	0.10	0.18	0.02
Letjen S Parman III	0.33	1.70	0.19	0.71	0.24
Letjen S Parman IV	0.09	0.90	0.10	0.16	0.01
Taman Indragiri	0.45	2.05	0.22	2.02	0.91
Industri Timur	0.30	1.70	0.18	0.45	0.13
Jl. Sulfat Agung	0.16	1.20	0.13	0.25	0.04

Based on Table 6, the water channel discharge value is influenced by the wet cross-section, wet perimeter, hydraulic radius, and flow speed. If the wet cross-section, wet perimeter, hydraulic radius, and flow velocity values are large then the channel has a large channel discharge. In the table above, Jalan Taman Indragiri has the largest channel discharge value compared to other areas.

Permeability Test

The permeability test was performed using the Inversed Auger Hole Method at the three locations of the study that were assumed to represent the results of the surrounding locations. The locations where the permeability test was carried out were Jalan Letjen S. Parman I, Jalan Taman Indragiri, and Jalan Aluminium in line with Table 7.

Table 7. Permeability Test Results

Location	Permeability Value	Type of Soil
Letjen S. Parman I	2.8×10^{-4} m/second	Fine Sand
Taman Indragiri	3.9×10^{-4} m/second	Fine Sand
Aluminium	1.6×10^{-4} m/second	Fine Sand

The results of the soil permeability test showed that the soil permeability value was in the range of 1.6×10^2 cm/second to 39×10^2 cm/second, so the soil type at the research location was fine sand. Fine sand has moderate permeability which means easy water absorption on moderate soil. Permeability has an important role in determining the rate of infiltration and movement of water into the soil.

Analysis of Infiltration Well Capacity

In analyzing the capacity of infiltration wells, the data required includes the dimensions of the infiltration well and the permeability coefficient, so that the total capacity is obtained which is the capacity of the infiltration well plus the capacity of the drainage channel as shown in Table 8.

Table 8. Infiltration Well Capacity

Location	n	V (m^3)	Vtotal (m^3)	Qwell (m^3/s)	Qtotal (m^3/s)
Indragiri V	2	1.51	3.01	0.05	0.09
Genuk Watu Barat	2	3.14	6.28	0.03	0.06
Letjen S. Parman I	7	4.71	32.97	0.05	0.34
Karya Timur I	1	2.36	2.36	0.01	0.01
Simpang Aluminium	1	3.14	3.14	0.01	0.01
Letjen S Parman III	2	3.14	6.28	0.03	0.06
Letjen S Parman IV	23	2.51	57.78	0.04	0.91
Taman Indragiri	1	2.36	2.36	0.05	0.05
Industri Timur	1	2.36	2.36	0.05	0.05
Sulfat Agung	2	3.14	6.28	0.01	0.02

Infiltration well discharge is influenced by depth, infiltration well geometry factors, and soil permeability coefficient. The discharge of the infiltration well is greater if the depth of the infiltration well is also greater. Meanwhile, total discharge is the discharge of all infiltration wells at the research location. The more infiltration wells there are, such as on Jalan Letjen S. Parman IV, the higher the total discharge value, so the capacity of the infiltration wells to accommodate and absorb water is greater.

Analysis of Design Flood Discharge

The method used in determining the design flood discharge is the Rational Method. There are three data used in this method, namely surface flow coefficient data (C), rain intensity (I), and water catchment area (A). By using the rational method formula, namely $Q_{ran} = 0{,}278 \times C \times I \times A$, the calculation is obtained as in Table 9.

Table 9. Analysis of Design Flood Discharge

Location	C	I	A	Qdes
Indragiri V	0.74	83.78	0.01	0.13
Genuk Watu Barat	0.78	124.39	0.01	0.18
Letjen S. Parman I	0.76	149.09	0.05	1.51
Karya Timur I	0.78	57.13	0.03	0.42
Simpang Aluminium	0.78	50.74	0.02	0.16
Letjen S Parman III	0.67	196.15	0.02	0.55
Letjen S Parman IV	0.76	166.95	0.04	1.38
Taman Indragiri	0.75	98.40	0.04	0.79
Industri Timur	0.62	130.32	0.03	0.63
Sulfat Agung	0.79	150.29	0.01	0.46

The flood discharge analysis was used to determine the magnitude of the design flood discharge at the study site. From Table 9 it is found that Letjen S. Parman IV has the largest design flood discharge value and Jalan Indragiri V has the smallest design flood discharge. A large design flood discharge indicates that the area is prone to flooding and waterlogging.

Infiltration Wells Effectiveness Analysis

The infiltration well effectiveness is obtained by comparing the discharge from the existing capacity of the infiltration well and the existing drainage channel discharge with the design flood discharge.

Table 10. Infiltration Wells Effectiveness Analysis

Location	Q_{des} (m^3/s)	Qinfiltration well (m^3/s)	Effectiveness (%)
Indragiri V	0.13	0.10	82.80
Genuk Watu Barat	0.18	0.08	47.20
Letjen S. Parman I	1.51	0.47	31.10
Karya Timur I	0.42	0.05	11.30
Simpang Aluminium	0.16	0.03	16.70
Letjen S Parman III	0.55	0.30	54.10
Letjen S Parman IV	1.38	1.06	76.80
Taman Indragiri	0.79	0.12	15.80
Industri Timur	0.63	0.17	27.70
Sulfat Agung	0.46	0.09	18.70

Based on Table 10, it can be concluded that the infiltration wells on Jalan Indragiri V are effective in reducing 82.8% of the total design flood discharge even though there are only 2 infiltration wells. This is because the drainage channels work well in the region. Meanwhile, on Jalan Karya Timur I, the infiltration wells were only effective in reducing 11.3% of the total design flood discharge. Some other regions also have an efficiency of less than 50 percent due to a shortage of infiltration wells. Apart from that, the presence of sediment is a factor causing infiltration wells to be less effective in several areas.

Infiltration well planning is expected to solve the waterlogging problem in Purwantoro Village. The lack of infiltration wells is one of the causes of frequent waterlogging. The number of infiltration wells required is calculated by comparing the optimal well depth to reduce inundation with the depth of the well to be planned.

The recommended number of infiltration wells at each study site differs depending on the amount of runoff discharge at that location. On Jalan Indragiri V, the recommended number of infiltration wells is 1 well with a depth of 3 meters and a diameter of 0.8 meters. On Jalan Indragiri V there are already 2 infiltration wells so there is no need for additional infiltration wells. Similarly, Jalan Letjen S. Parman IV has 23 existing infiltration wells, while the recommended infiltration wells are 8 infiltration wells, so no additional additions are needed. Another case with other locations that require the addition of infiltration wells because the recommended number is still not met, such as on Jalan Karya Timur I involves the addition of 20 infiltration wells with a diameter of 1 meter and a depth of 6 meters.

Table 11. Infiltration Wells Planning

Location	D_{plan} (m)	H_{plan} (m)	Total	Exist	Add
Indragiri V	0.8	3	1	2	0
Genuk Watu Barat	1	4	3	2	1
Letjen S. Parman I	1	6	21	7	14
Karya Timur I	1	6	21	1	20
Simpang Aluminium	1	5	9	1	8
Letjen S Parman III	1	4	8	2	6
Letjen S Parman IV	0.8	5	8	23	0
Taman Indragiri	1	5	9	1	8
Industri Timur	1	3	10	1	9
Sulfat Agung	1	6	21	2	19

Changes in land use affect the absorption of rainwater, resulting in flooding in urban areas. Infiltration wells have a positive impact on reducing surface runoff and flood risk as well as groundwater recharge (Nachshon et al., 2016). In addition, extreme rainfall also increases the risk of urban flooding, but the use of infiltration wells can reduce flood risk by up to 40% (Netzer et al., 2024). The application of infiltration wells can reduce the discharge and peak volume of floods by 31.24%, so that the construction of infiltration wells can maintain water sustainability and reduce flood risk (Pamungkas et al., 2023). The addition of infiltration wells requires careful technical planning and strong local regulations to ensure the successful and sustainable implementation of the proposed solution (Aloui et al., 2024). Government policies are critical in institutional arrangements, infiltration well construction design, and infiltration well operations such as ongoing maintenance so that infiltration wells can function effectively (Edwards et al., 2022; Page et al., 2023). Simple but effective infiltration wells for reducing flood risk will facilitate the community's construction and maintenance (Muntaha et al., 2022). In addition to flood control, infiltration wells are used to recharge groundwater, so the right location must be planned (Alam et al., 2021; Aloui et al., 2024; Mouhoumed et al., 2023; Page et al., 2023; Sultana et al., 2024). With proper planning, it is hoped that the problem of waterlogging in Purwantoro Village can be resolved.

Conclusion

The construction of infiltration wells is one alternative to reducing waterlogging. The effectiveness of existing infiltration wells in Purwantoro Village varies greatly, with the highest at 82.8% and the lowest at 11.3%. The number of infiltration wells and the conditions of the infiltration wells cause differences in effectiveness. To optimize the use of infiltration wells as a waterlogging solution, proper planning is crucial. Infiltration well planning is carried out by adding infiltration wells according to the conditions of each region. At the research site, it is necessary to add 109 infiltration wells with infiltration well diameters between 0.8 meters to 1 meter and infiltration well depths between 3 meters to 6 meters. As a policy maker, the government must prioritize the handling of waterlogging through the development of infiltration wells. The government can also cooperate with the private sector and the community in making infiltration wells so that infiltration wells can be evenly distributed in each region and by the planned number of infiltration wells needed. It is also important to socialize with the community about the maintenance of infiltration wells and the benefits of infiltration wells in reducing waterlogging. The role of the community is needed in maintaining infiltration wells so that the infiltration wells that have been built can optimally reduce waterlogging in the long term by the expected age of infiltration wells. This research is limited by the research area of only one village so conditions in other areas may be different from Purwantoro Village. Thus, it is expected that there will be research in a wider area so that the policies made can be implemented up to the city level.

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Author Contributions
Conceptualization, O.M., M.K., V.D. and B.H.; methodology, O.M.; validation, M.K., V.D. and B.H.; formal analysis, O.M.; investigation, O.M.; resources, O.M.; data curation, M.K., V.D. and B.H.; writing—original draft preparation, O.M; visualization, M.K., V.D. and B.H. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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