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Regional Case Study

Infiltration Well Design for Environmental Conservation: Assessing Watershed and Groundwater Depth in Denpasar City

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Abstract

Urbanization and climate change are expected to exacerbate and introduce uncertainty in future flood characteristics. The city of Denpasar often experiences flooding due to rapid population growth and changes in land use. One form of flood mitigation that can be implemented is infiltration wells. This research aims to design infiltration wells as an environmental conservation effort by evaluating the characteristics of the watershed and the depth of groundwater. This research will also examine lithological aspects and use geographic information systems (GIS) to increase effectiveness in planning. The research results show that the construction of infiltration wells at the research location is effective in reducing flood volume, with reductions varying between 19.86% in South Denpasar and 59.58% in North Denpasar, East Denpasar and West Denpasar. Infiltration wells not only reduce the risk of flooding but also play an important role in preserving the environment according to the Tri Hita Karana concept. By integrating these sustainable practices into spatial planning, water resource management can be enhanced, fostering a healthy environment for future generations.

Keywords: Infiltration wells; floods; watershed; groundwater depth; lithology; geographic information systems.

1. Introduction

Flooding is a natural disaster that often occurs, especially in lowlands and around river flows, with the main causes being high rainfall, changes in land use, and poor drainage systems. Intense rainfall increases surface runoff, especially when the soil cannot absorb water optimally. Additionally, uncontrolled deforestation and urbanization reduce the soil's ability to absorb water, exacerbating the risk of flooding (Wang et al., 2023)On the other hand, urbanization and climate change are expected to worsen and introduce uncertainty in the characteristics of future floods, so flood damage mitigation needs to be adapted to deal with these conditions (Pariartha, 2019). Denpasar City is the capital of Bali Province which is experiencing rapid population growth with a growth rate of 0.12% per year, increasing the population to 726,800 people in 2022, with a density of 5,770 people per km^2. This growth causes water catchment areas to turn into residential areas and other facilities, increasing the risk of urban flooding and exacerbating infrastructure losses, especially during high rainfall (Pariartha, 2019).

The Denpasar City area has a very high flood risk, according to a report by the Denpasar City Disaster Management Agency (BPBD) in 2021, 37 flood incidents occurred in Denpasar City. These findings align with the Denpasar City Flood Hazard Map by the National Disaster Management Agency

(BNPB) of Bali Province (BNPB, 2024), which shows that 22.04% of the Denpasar City is classified as a flood-prone area and makes it the area with the highest percentage of flood-prone areas. Therefore, Denpasar should serve as a model for effective and sustainable environmental management to enhance the effectiveness of flood mitigation strategies.

There are various forms of flood mitigation that can be implemented, such as the construction of canals, drainage improvements, and the creation of retention ponds. However, infiltration wells are considered superior because they enhance water infiltration into the ground, reduce the burden on drainage systems, and support sustainable groundwater conservation (Tumpu et al., 2022). Additionally, infiltration wells require relatively less space and can be applied directly in residential areas, making them an effective and environmentally friendly solution for flood control. This approach aligns with government initiatives to mitigate flood risks involving the implementation of green economy principles. The green economy is defined as an economic strategy focused on enhancing human welfare and promoting social equity while significantly minimizing environmental impact (Setiawan et al., 2020). The water resource management strategy in the Bali-Penida River Region has adopted a conservation-based approach to reduce flood risks in Denpasar City, forming part of broader water resource conservation efforts (Balai Wilayah Sungai Bali-Penida, 2019). According to Denpasar City Regional Regulation No. 5 of 2015 concerning buildings, infiltration wells serve a function related to green open spaces (Walikota Denpasar, 2015). Furthermore, infiltration wells comply with other governmental regulations, such as Denpasar Mayor Regulation Number 18 of 2010 and the Minister of the Environment Regulation Number 12 of 2009, which govern water resource conservation linked to rainwater utilization (Menteri Negara Lingkungan Hidup, 2009; Walikota Denpasar, 2010). The function of infiltration wells is to absorb rainwater into the ground, thereby preventing surface runoff. On the other hand, the absorbed rainwater will be used to recharge groundwater reserves, which is crucial for maintaining ecosystem balance and meeting the water needs of the community in the area. Thus, infiltration wells not only serve as a solution to reduce flood risks but also contribute to the sustainability of water resources in the surrounding environment (Tumpu et al., 2022).

The infiltration well conservation method has been widely adopted in dealing with flood problems, such as in Jakarta (Januriyadi et al., 2019; Situmorang et al., 2021), Cirebon (Mulyono et al., 2021), Amlapura (Yekti et al., 2021) and Denpasar (Pamungkas et al., 2023b). Although these studies indicate that infiltration wells can significantly reduce flooding, their application is generally limited to small and regional scales. Therefore, further research is needed to explore the effectiveness of infiltration wells at a broader scale, such as the entire city. Additionally, the development of more detailed planning based on watershed management is crucial to optimizing the planning of infiltration wells through the, regulation, integration of culture and digitization.

The concept of Tri Hita Karana, derived from, Balinese cultural philosophy, emphasizes the importance of harmony among humans and God (Parahyangan), humans and fellow humans (Pawongan), and humans and nature (Palemahan) in daily life (Wiranata, 2021). This philosophy is relevant to the sustainable management of water resources, where a harmonious relationship among humans, nature, and faith in God is essential for maintaining ecosystem balance. In the context of flood mitigation, Tri Hita Karana is manifested through infiltration wells that return rainwater to the ground, helping to preserve groundwater reserves and respecting the natural water cycle. This approach encourages communities to maintain a positive relationship with the environment, understanding that every conservation effort, including the use of infiltration wells, represents a form of respect for God and a responsibility in environmental preservation.

In the context of digitalization, the planning analysis process for absorption wells will utilize GIS, an information system designed to work with spatial data sources. This GIS will be used to analyze built-up land to produce watershed-based research location maps and residential land use maps. Several previous studies have applied GIS in land cover analysis, such as in East Java (Rif'ati et al., 2023), Sumbawa (Indrajaya, 2021) and Turkey (Sultana et al., 2022). Apart from that, an important factor in planning infiltration wells is the infiltration capacity which is determined by the type of rock/soil. Litological studies in the form of groundwater level investigations and laboratory tests to determine soil permeability are essential for producing detailed information about rock structures/geology. This is important in optimizing the effectiveness of groundwater absorption by the soil layer. Watershed adjustments and specific geological types are not yet included in the SNI 03-2453-2002 standard which regulates procedures for planning rainwater absorption wells for homesteads (Badan Standardisasi Nasional, 2002).

Based on the existing background, although the benefits of infiltration wells in mitigating flood risks have been proven in various regions, their application remains limited to small and regional scales. Therefore, further research is needed to assess the effectiveness of infiltration wells on a larger city scale. In addition, existing studies have not fully integrated watershed management, cultural integration, and digitalization into comprehensive planning. This research aims to bridge that gap by exploring the planning of infiltration wells in Denpasar City, focusing on the characteristics of the watershed and lithological factors, as well as utilizing Geographic Information Systems (GIS) for spatial analysis. This innovative approach emphasizes the importance of detailed planning based on local geological conditions and aligns with the Tri Hita Karana philosophy, which promotes harmony between human activities and nature. By integrating these elements into the planning process, this study aims to enhance flood mitigation strategies and optimize water resource management in Denpasar, creating a healthy and sustainable environment for future generations.

2. Methods

In this study, quantitative descriptive analysis was the methodology employed. By taking into account the features of the watershed and the kind of soil lithology, this analysis seeks to determine and characterize the efficacy of infiltration wells in lowering the danger of floods in Denpasar City. The focus of this research is on environmental management efforts to reduce the risk of flooding in Denpasar City by increasing infiltration capacity in the watershed through the implementation of infiltration wells. For this reason, more detailed planning development is needed, including integration of Geographic Information Systems (GIS), adjustments to watershed mapping, as well as digital lithology investigations to increase its effectiveness. The following are the research stages that will be implemented to achieve the research objectives, divided into two important parts, data collection and data analysis.

Data collection in this research includes primary and secondary data. The primary data required consists of ground water depth data and lithology data obtained through geoelectric testing in the four sub-districts in Denpasar City. Apart from that, secondary data is also needed as a basis for Geographic Information System (GIS) analysis, which is taken from the web portal of the Geospatial Information Agency, as well as hydrological analysis data from the Bali-Penida River Basin Organization and soil classification data for planning infiltration wells obtained from soil type maps.

The data analysis in this study includes several stages such as geological analysis, GIS data analysis, hydrological analysis, and infiltration well analysis. Geological analysis relies on primary data from groundwater level investigations and laboratory tests on soil permeability, along with secondary data from soil type maps provided by the Ministry of Energy and Mineral Resources (ESDM). This information is utilized to determine the values of the runoff coefficient, soil permeability coefficient, and groundwater depth for planning infiltration wells, conforming to SNI 2415-2016 (Badan Standardisasi Nasional, 2016), Denpasar Mayor Regulation Number 18 of 2010 (Walikota Denpasar, 2010), and SNI 03-2457-2002 (Badan Standardisasi Nasional, 2002). GIS data analysis is conducted using secondary data from the Geospatial Information Agency, specifically administrative data. This data helps to identify watershed areas and perform residential land cover analysis, supported by landform data, to produce maps of research locations based on watershed characteristics and residential land use within the study area. During the GIS data analysis phase, collaboration with a remote sensing expert will be implemented to ensure accuracy in results. Hydrological data analysis is derived from secondary data provided by the Bali-Penida River Basin Organization and the Meteorology, Climatology, and Geophysics Agency Region

3, in addition to the results of GIS data analysis. This data serves to determine regional rainfall, planned rainfall, and flood discharge that occurs within the study area. Infiltration well analysis is based on the findings from the hydrological, GIS, and geological data analyses, which are subsequently adjusted according to SNI 03-2453-2002 (Badan Standardisasi Nasional, 2002), which governs infiltration well planning for home gardens. The final analysis results focus on the efficiency of infiltration wells in reducing flood discharge and volume. Planning for these infiltration wells is intended to be a community-driven effort, relying on the residential yards of local areas, similar to previous studies conducted in a small section of Denpasar City (Pamungkas et al., 2023b) and in Amlapura City, Karangasem (Yekti et al., 2021).

2.1. Research Location

The research location is located in Denpasar City, which is in the south of Bali Island. As illustrated in Figure 1, this research site traverses nine distinct watershed areas, including the Abianbasa watershed, the Ayung watershed, the Badung watershed, the Buaji watershed, the Loloan watershed, the Mati watershed, the Ngenjung watershed, the Serangan watershed, and the Singapadu watershed.

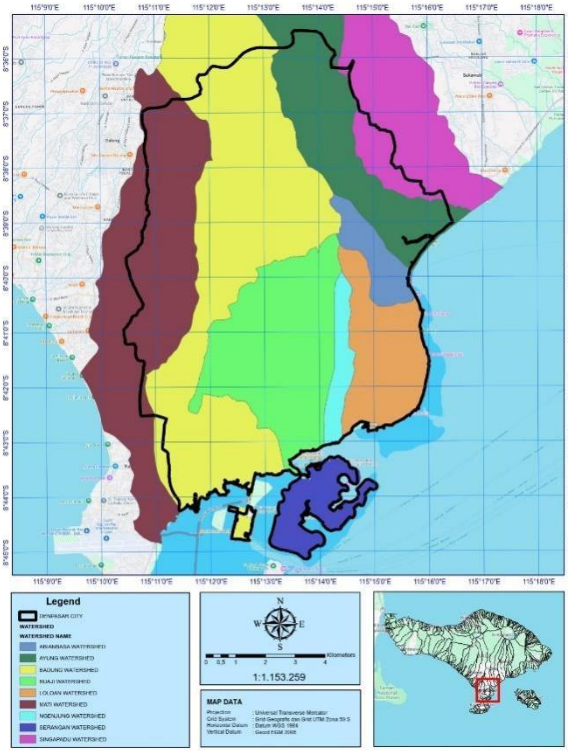


Figure 1. Denpasar Region Watershed Map

2.2. Built-up Land Analysis with Geographic Information Systems (GIS)

Land cover analysis using Geographic Information Systems (GIS) aims to identify types of land use in an area and monitor changes over time. This process involves processing satellite images and base maps to produce accurate land cover maps. The steps required to analyze built-up land using GIS include data collection where the data used in this analysis is in the form of satellite images and supporting maps such as administrative boundaries. The initial processing of satellite image data requires gap filling in damaged satellite images using two images from different times. The image with the best condition is selected as the main image while the other images are used to fill in the missing parts.

Before cropping, it is necessary to ensure the similarity of the projection system and datum between satellite image data and vector data. If the vector format is not suitable, conversion is carried out so that the image can be cropped according to the research area. Supervised classification involves classifying satellite images using the Minimum Distance method which measures the distance from the center value of the training area. If the accuracy of the classification results is below the specified threshold, this process needs to be repeated to improve the quality of the classification. The conversion of raster data to vector data is necessary as classified raster data is converted into vector data to facilitate the calculation of the area of various land cover classes while also aiding in the further analysis process.

Cloud cover generation determines whether regions are cloud-covered to prevent them from being mistakenly labeled as different kinds of land cover as the technology aids in separating the earth and clouds. Following classification, the correction of classification results requires manual verification by contrasting them with the original image. This step ensures that the categorization results are as close to the actual conditions as possible while any inaccuracies are corrected. Finally, after the land cover data has been corrected, the calculation of land cover area combines and simplifies each class using spatial data processing tools to ensure that the area of each land cover class can be calculated accurately.

2.3. Geological Data Analysis

Geological analysis has an important role in planning infiltration wells because data related to soil properties such as permeability and groundwater depth are used to evaluate water infiltration efficiency. Understanding local geological conditions, including soil permeability values and groundwater depth, allows optimization in the design of infiltration wells so that they can absorb maximum water. In this research, geological analysis is based on primary data from groundwater level investigations and laboratory tests on soil permeability, as well as secondary data on soil type maps from the Ministry of Energy and Mineral Resources (ESDM). This data is used to determine the value of the soil permeability coefficient and groundwater depth, which is then adjusted to the applicable regulations in planning infiltration wells. Soil permeability is the speed of fluid movement through porous media, in this case, defined as the speed of water flowing through the soil within a certain period (Mulyono et al., 2019). Calculation of soil permeability coefficient based on SNI 03-2453-2002 (Badan Standardisasi Nasional, 2002) is calculated using Equation 1:

$$K_{average} = \frac{K_v.A_h + K_h.A_v}{A_{total}} \quad (1)$$

Details:

$K_{average}$ = average soil permeability coefficient (m/day)

K_v = soil permeability coefficient on the walls of the infiltration well (m/day)

K_h = soil permeability coefficient at the base of the infiltration well (m/day)

A_v = area of the infiltration well wall (m^2)

A_h = area of the base of the infiltration well (m^2)

2.4. Hydrological Analysis

Hydrological analysis is done step-by-step with acquired secondary data. The nearest rain station's highest daily rainfall data for the previous ten years is the basis for the analysis of regional rainfall estimations. To eventually gather data on the maximum rainfall and predicted flood discharge in this analysis, a few processes must be undertaken. The hydrological analysis in this research is as follows:

Rain data reliability test

This test was carried out at each station using the Rainfall-Runoff Analysis and Prediction System (RAPS) method with Equations 2 to 7.

$$So^* = 0 \quad (2)$$

$$Sk^* = \sum_{i=1}^{k} (\bar{Y} - Yi) \text{ k} = 1,2 \quad (3)$$

$$Sk^{**} = \frac{Sk^*}{Dy} \quad (4)$$

$$Dy^2 = \sum_{i=1}^{n} \frac{(Yi - \bar{Y})}{n} \quad (5)$$

Statistical value

$$Q = Max\ |Sk^{**}| \tag{6}$$
$$0 \leq k \leq n$$
$$R = Max\ Sk^{**} - Min\ Sk^{**} \tag{7}$$

Details:
So = infiltration rate
Sk = rainfall deviation
Q = surface runoff
R = rainfall
Yi = rainfall data
$\underline{Y}$ = average rainfall data
Dy = standard deviation
n = number of data

Frequency Distribution Analysis

There are various frequency distribution methods, but the most commonly used in hydrology include the Normal method, Log-Normal method, Gumbel method, and Log Pearson III method. In this research, the frequency distribution analysis used is the Log Pearson III method, explained further through the following steps:
Convert the data into logarithmic form using Equation 8.

$$X = logX \tag{8}$$

Calculate the average logarithm using Equation 9.

$$log\bar{X} = \frac{\sum_{i=1}^{n} log\ Xi}{n} \tag{9}$$

Calculate the standard deviation using Equation 10.

$$S = \frac{\sqrt{\sum_{i=1}^{n}(Log\ Xi - X)^{\bar{2}}}}{(n-1)} \tag{10}$$

Calculate the deviation coefficient using Equation 11.

$$Cs = \frac{n.\sum_{i=1}^{n}(Log\ Xi - X)^3}{(n-1)(n-2)S^3} \tag{11}$$

Details:
n = number of years reviewed
S = standard deviation (mm)
$\underline{X}$ = average rainfall (mm)
Xi = maximum rainfall (mm)
Cs = skewness coefficient

Calculation of Average Rainfall for 5-Years Period

The calculation of rainfall distribution is adjusted according to the available rainfall data based on the suitability test for the selection of the distribution method, resulting in the average daily maximum rainfall for each month for a return period of 5 years across the entire area of Denpasar City.

Inverse Distance Weighting (IDW) Analysis

The Inverse Distance Weighting (IDW) method is an interpolation technique that estimates the value of a variable at a specific location by giving more weight to nearby observation points, assuming closer points have a stronger influence than those further away (Warsana, 2024). The IDW method has been widely used for mapping rainfall patterns due to its accuracy in estimating rainfall values across various locations based on data from nearby observation stations. Previous studies, such as those by (Bahtiar et al., 2022), (Marthadyanti et al., 2024) and (Susanto et al., 2024) have successfully applied the IDW method to create detailed rainfall distribution maps. These studies demonstrate that IDW can effectively represent spatial rainfall variability, making it a valuable tool in hydrological modeling and disaster mitigation planning.

After the maximum rainfall data in Denpasar City was obtained, the data was interpolated using the Inverse Distance Weighting method in GIS. First, a new worksheet was created. Next, the average daily maximum rainfall data for each month over a period of 10 years was entered into the GIS application. Administrative map layers and base map layers were then added to the GIS application. Spatial analysis was conducted using the IDW method based on Equation 12. Following that, classification and symbology settings were performed. Information was added to the Table attributes. Layouts were created. Finally, the map was exported as an image in JPEG format.

$$Z_p = \frac{\sum_{i=1}^{n}\left(\frac{z_i}{d_i^p}\right)}{\sum_{i=1}^{n}\left(\frac{1}{d_i^p}\right)} \quad (12)$$

Details:
Z_p = the estimated value at the target point "p"
Z_i = the value at the observation point "i"
d_i = the distance between the target point ppp and the observation point "i"
p = the weighting exponent (p = 2) can be set to give more influence to closer points
n = the number of observation points considered in the calculation

2.5. Infiltration Well Analysis

Every sub-watershed in the research area will have an infiltration well analyzed, and the analysis's findings will be presented as discharge and flood volume that infiltration wells can potentially lower. The purpose of infiltration wells is to collect and absorb rainfall into the earth. The analysis in this study was modified to comply with SNI 03-2453's guidelines for designing rainwater absorption wells for yard areas (Badan Standardisasi Nasional, 2002). Equation 13 is utilized in the computation of the flood contribution volume:

$$V_{ab} = 0{,}855.\,C_{container}.\,A_{container}.\,R \quad (13)$$

Details:
V_{ab} = the amount of flood sharing that infiltration wells can handle (m^3)
$C_{container}$ = coefficient of drainage from the catchment area (without units)
$A_{container}$ = area of containers (m^2)
R = average height of rain per day (L/m^2/hari)
Equation 14 is used to calculate the volume of pervasive rain.

$$V_{rsp} = \frac{t_e}{R} . A_{total} . K \tag{14}$$

Details:

V_{rsp} = pervasive volume of rainwater (m^3)

t_e = duration of the rain effectively (hour) = 0.9 x R0.92 /60 (hour)

R = average height of rain per day (L/m^2/day)

A_{total} = infiltration well wall area + infiltration well bed area (m^2)

K = coefficient of soil permeability (m/day)

To calculate the required number of rainwater infiltration wells, start by determining H_{total} using Equation 15, followed by applying Equation 16.

$$H_{total} = \frac{V_{ab} - V_{rsp}}{A_h} \tag{15}$$

$$n = \frac{H_{total}}{H_{plan}} \tag{16}$$

Details:

n = number of wells for rainfall infiltration (units)

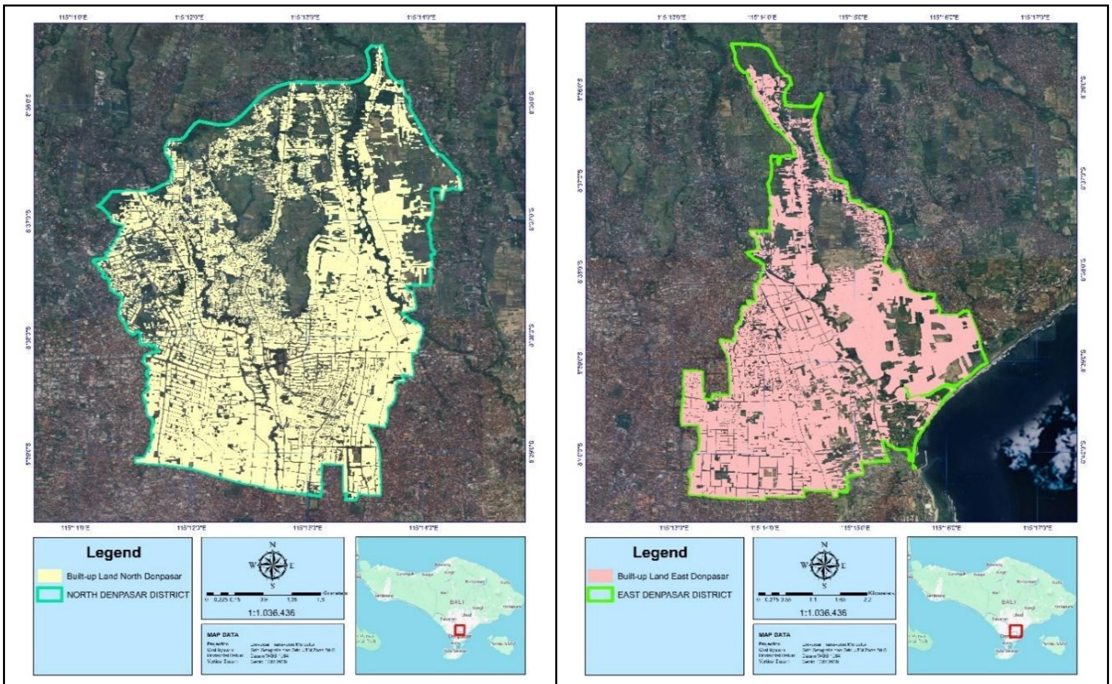
H_{total} = rainwater infiltration wells' total depth (m)

H_{plan} = planned depth < groundwater depth (m)

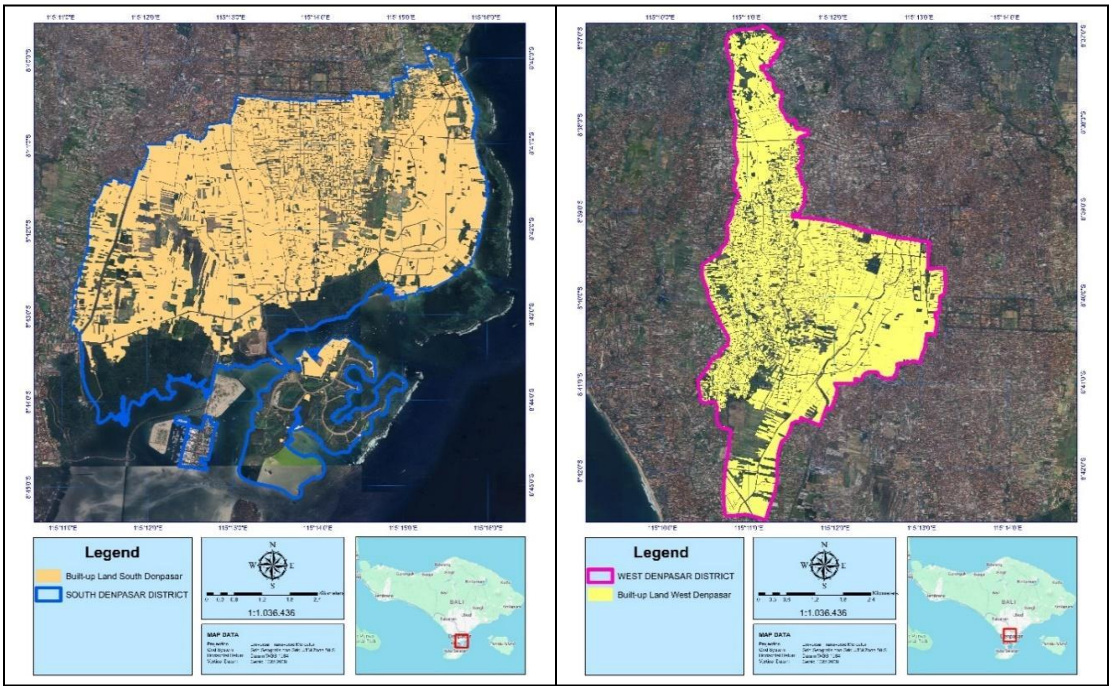
3. Result and Discussion

3.1. Built-up Land Analysis

The mapping analysis conducted is a land cover analysis based on satellite imagery maps in the study area, which is the Denpasar City region, as shown in Figure 2. In this figure, it can be seen that the built-up land in North Denpasar is 14,915,569 m², East Denpasar is 15,554,482 m², West Denpasar is 17,831,123 m², and South Denpasar is 5,942,261 m².



North Denpasar	East Denpasar



South Denpasar	West Denpasar

Figure 2. Results of built-up land analysis in Denpasar City

3.2. Geological Analysis

The geological analysis in the planning of infiltration wells includes groundwater level and permeability coefficient. Based on the groundwater level investigations, the average depth of groundwater in each subdistrict of Denpasar City is presented in Table 1. Additionally, referring to the results of laboratory tests on 3 soil samples at a depth of 2 meters, the soil permeability coefficient was obtained at 0.004 cm/second or 14.28 cm/hour. Furthermore, the average permeability coefficient can be determined using Equation 1, with the results displayed in Table 1.

Table 1. Groundwater level and average permeability coefficient in Denpasar City

No	Subdistrict	Average Groundwater depth (m)	Average permeability coefficient (K)
1	North Denpasar	5.6	3.428
2	East Denpasar	4.1	3.428
3	West Denpasar	7.4	3.428
4	South Denpasar	1.5	3.428

3.3. Hydrological Analysis

Hydrological analysis begins by determining the rain station used in the research. In this research, six rain stations were selected for data collection. The six stations are Penatih Station, Ubung Station, Sumerta Station, Sanglah Station, Buagan Station, and Suwung Station, where the location of each station has been mapped as shown in Figure 3.

Figure 3. Rain station locations used in the analysis

After that, rainfall data from the six rain stations was analyzed to obtain planned rainfall values. Calculation of rainfall distribution according to existing data was carried out using the Log Pearson Type III method. Referring to the planned rainfall data for the 5-year period, analysis was conducted to determine the interpolation results using the IDW method. The IDW method assumes that each input point has a local influence that diminishes with distance. The influence will be greater from input points that are closer, resulting in a more detailed surface (Warsana, 2024). The following visualization form of planned rainfall for a 5-year period in Denpasar City is explained in Figure 4.

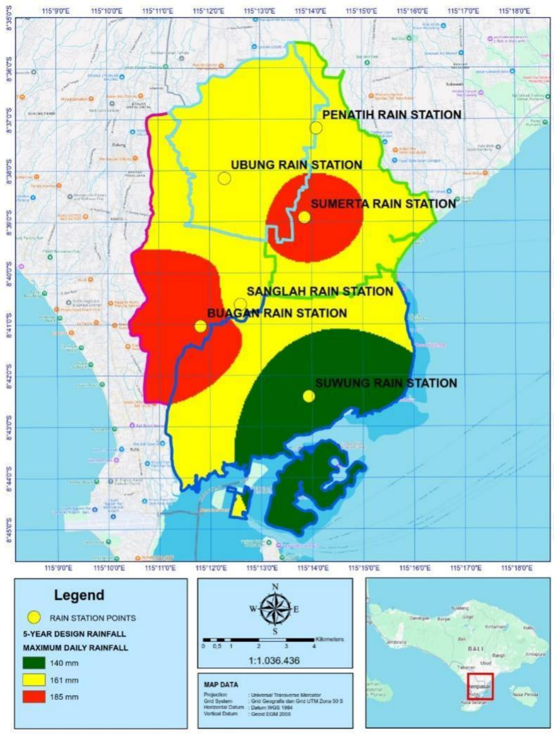


Figure 4. Rainfall plan for 5-year return period

3.4. Infiltration Well Analysis

The first step in the analysis of infiltration well planning is to calculate the volume of flood contribution at the study location using Equation 13. Based on previously obtained parameters such as the runoff coefficient from the catchment field ($C_{container}$), the area of the catchment field (Catchment area), and the rainfall for a 5-year period (R5), the volume of flood contribution is obtained in each sub-district as listed in Table 2.

Table 2. Volume of flood contribution in Denpasar City

No	Subdistrict	$C_{container}$	Catchment Area (m²)	R5 (mm)	V_{ab}
A	B	C	D	E	F = (0.855*C*D*E)
1	North Denpasar	0.75	14,915,569	185	1,769,453
2	East Denpasar	0.75	15,554,482	185	1,845,248
3	West Denpasar	0.75	25,942,261	185	3,077,563
4	South Denpasar	0.75	17,831,123	185	2,115,328

The next step is to determine the dimensions of the absorption well to be used and how much volume of flood contribution can be absorbed. Determining the dimensions of infiltration wells is based on SNI 03-2453-2002 with parameter values in the form of groundwater depth. In the study area, it was found that the groundwater depth in Denpasar City ranged from 1.5 m – 7.4 m, this is in accordance with the technical requirements for infiltration wells (Badan Standardisasi Nasional, 2002; Yekti et al., 2021). Based on these considerations, the dimensions of the absorption wells and the volume of flood contribution that can be absorbed (V_{rsp}) are obtained, which are listed in Table 3.

Table 3. Volume of flood contribution that can be absorbed

No	Subdistrict	Dimensions (concrete masonry)	$V_{infiltration\ wells}$ (m³)	V_{rsp} (m³)
1	North Denpasar	Diameter =100 m; Height = 3 m	2.356	2.67
2	East Denpasar	Diameter =100 m; Height = 3 m	2.356	2.67
3	West Denpasar	Diameter =100 m; Height = 3 m	2.356	2.67
4	South Denpasar	Diameter =100 m; Height = 1 m	0.785	1.03

Referring to Table 3, the height of the concrete masonry used for the infiltration wells varies. In North Denpasar, West Denpasar, and East Denpasar, the height used is 3 meters due to the groundwater level being deeper than that. Meanwhile, South Denpasar has a groundwater level of 1.5 meters, which limits the depth of the constructed infiltration wells to only 1 meter.

Based on Table 3 as well, an analysis of the infiltration wells was carried out. This analysis was conducted to determine how many infiltration wells are needed for a 5-year return period rainfall of 185 mm on a built-up area of 100 m². The analysis is divided for North Denpasar, East Denpasar, and West Denpasar, which are listed in Table 4, and the analysis for South Denpasar, which is listed in Table 5.

Table 4. Analysis results of infiltration wells for R5 in the North Denpasar, East Denpasar and West Denpasar areas

No	Description	Result	Unit
1	Calculation of Flood Contribution Volume (Equation 13)	11.863125	m³
2	The amount of rain that infiltration wells can hold is calculated (Equation 14)	2.67	m³
3	Number of infiltration wells (Equation 14 and Equation 16)	4	unit

Table 5. Analysis results of infiltration wells for R5 in the South Denpasar

No	Description	Result	Unit
1	Calculation of Flood Contribution Volume (Equation 13)	11.863125	m^3
2	The amount of rain that infiltration wells can hold is calculated (Equation 14)	1.03	m^3
3	Number of infiltration wells (Equation 14 and Equation 16)	14	unit

Referring to Denpasar City Regional Regulation No. 5 of 2015 concerning Buildings (Walikota Denpasar, 2015) it is explained that there must be a minimum of 15% green open space on built-up land/private land. The green open space in question includes places where plants grow, water infiltration, circulation, and other activity spaces. Considering the other functions of green open space that must be accommodated, it is assumed that only 1 m^2 or as many as 3 infiltration wells can be built on an area of 100 m^2. Thus, the total number of infiltration wells that must be built in Denpasar City can be known and is listed in Table 6.

Table 6. Results of calculating the number of infiltration wells in Denpasar City

No	Subdistrict	Number of Infiltration Wells (per 100 m^2)	Catchment Area (m^2)	Total Number of Infiltration Wells
A	B	C	D	E= C*D/100
1	North Denpasar	3	14,915,569	447,468
2	East Denpasar	3	15,554,482	466,635
3	West Denpasar	3	17,831,123	534,934
4	South Denpasar	3	25,942,261	778,268

Calculating how well infiltration wells reduce flooding over a 5-year return period is the last phase. Table 7 through Table 10 show the results of the calculations that were done for each subdistrict in Denpasar City.

Table 7. Calculation of the effectiveness of infiltration wells in North Denpasar District

No	Description	Result	
1	The amount of water that infiltration wells can hold is calculated (V infiltration wells x total number of wells)	1,054,321.64	m^3
2	Flood sharing volume calculation (*Table* 2)	1,769,453	m^3
3	Percentage of efficiency (Result 1 / Result 2)	59.58%	

Table 8. Calculation of the effectiveness of infiltration wells in East Denpasar District

No	Description	Result	
1	The amount of water that infiltration wells can hold is calculated (V infiltration wells x total number of wells)	1,099,482.82	m^3
2	Flood sharing volume calculation (*Table* 2)	1,845,248	m^3
3	Percentage of efficiency (Result 1 / Result 2)	59.58%	

Table 9. Calculation of the effectiveness of infiltration wells in West Denpasar District

No	Description	Result	
1	The amount of water that infiltration wells can hold is calculated (V infiltration wells x total number of wells)	1,260,408.54	m^3
2	Flood sharing volume calculation (*Table* 2)	2,115,328	m^3
3	Percentage of efficiency (Result 1 / Result 2)	59.58%	

Table 10. Calculation of the effectiveness of infiltration wells in South Denpasar District

No	Description	Result	
1	The amount of water that infiltration wells can hold is calculated (V infiltration wells x total number of wells)	611,250.26	m^3
2	Flood sharing volume calculation (*Table* 2)	3,077,563	m^3
3	Percentage of efficiency (Result 1 / Result 2)	19.86%	

The construction of infiltration wells at the research location can reduce flood volume with varying reduction effectiveness, starting from 19.86% in South Denpasar and 59.58% in North, East, and West Denpasar, according to the results of the calculation analysis in Table 7 to Table 10 above. Absorption wells in West Denpasar decreased the volume of flood runoff by as much as 51.38%, according to earlier study (Pamungkas et al., 2023a). Additional research conducted in the Denpasar City region demonstrates that the Ngenjung watershed in South Denpasar can effectively reduce

flood volume by up to 31.24% through the planning of infiltration ponds (Pamungkas et al., 2023b).

This research shows that infiltration wells play an important role in preserving the environment and managing water resources, in line with the principle of green open space, which has many functions, including as a water catchment area and storage of water reserves (Mahdiyah et al., 2022). This research uses an analytical approach emphasising the sustainable application of infiltration wells in urban drainage systems. This concept is part of "Low Impact Development" (LID), which aims to support the conservation of water resources by keeping natural and hydrological conditions the same as before construction (Anwar, 2019; Nurhamidah et al., 2023; Suprapti et al., 2024). By integrating infiltration wells in spatial planning, we can increase groundwater infiltration and reduce surface runoff, supporting urban ecosystems' sustainability. In addition, implementing infiltration wells helps maintain environmental functions, such as providing green open space that functions for water absorption, reducing the risk of flooding, preserving groundwater resources, and improving environmental quality (Tumpu et al., 2022).

The integration of infiltration wells with the philosophy of Tri Hita Karana, which emphasizes harmony among humans, nature, and God, supports environmental balance. In this context, the construction of infiltration wells can be seen as an effort to honor the harmonious relationship among these three elements. The application of the Tri Hita Karana concept in the planning of infiltration wells can enhance water infiltration and reduce runoff, thereby contributing to the sustainability of urban ecosystems. In addition to functioning to reduce flood risks, infiltration wells also create opportunities for communities to actively participate in environmental stewardship, reflecting the social and cultural values inherent in this philosophy. By integrating the values of Tri Hita Karana into the management of infiltration wells, we can achieve true sustainability and harmony with nature.

4. Conclusions

The construction of infiltration wells at the research location showed significant effectiveness in reducing flood volume, with reductions varying between 19.86% in South Denpasar and 59.58% in North Denpasar, East Denpasar, and West Denpasar. This effectiveness is based on planning that uses in-depth lithological analysis and is based on Geographic Information Systems (GIS), ensuring that the location and design of infiltration wells are appropriate to the area's soil characteristics, groundwater table conditions, and hydrological conditions. With this approach, infiltration wells can function optimally to reduce the risk of flooding and increase groundwater infiltration. Therefore, to reduce flooding optimally in Denpasar City in a sustainable manner, this research can be used as a reference in designing environmentally friendly drainage concepts.

Apart from technical benefits, infiltration wells also play an important role in preserving the environment. They align with the Tri Hita Karana concept, prioritising balance between humans, nature, and God. Implementing infiltration wells reflects efforts to maintain ecosystem harmony while supporting the principles of green open space. By integrating these sustainable practices in spatial planning, we improve water resource management and contribute to community welfare and environmental conservation. This aligns with efforts to create a healthy and sustainable environment for future generations.

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