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Research Article

Surface Runoff Analysis for Infiltration Well to Maintain Groundwater Availability

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Abstract.
Rapidly increasing housing demand has led to significant land-use changes, even in rural areas like Pakintelan Village. One major consequence of these changes is increased surface runoff, which can contribute to environmental issues. This study aims to analyze the surface runoff in Pakintelan Village and estimate the number and placement of infiltration wells needed to effectively manage the runoff. Using a combination of arithmetic methods based on rational equations and Geographic Information System (GIS) tools, the research identified the main catchment areas in Pakintelan Village. The GIS data used in the analysis had a vertical accuracy of 50 cm and a horizontal accuracy of 7 cm. The results show that the village produces approximately 3.89 m3/sec of runoff, with the majority originating from mixed garden areas. To mitigate this, infiltration wells should be placed at the lowest location in these mixed gardens to reduce surface runoff. This study provides a novel assessment of runoff and water absorption strategies in Pakintelan Village, offering practical insights for future land and water resource management in similar settings.

Keywords: GIS, land use change, surface runoff

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1. Introduction

Increasing population growth causes land conversion due to rising demand for settlements (1). Land that was originally agricultural land or forest turned into an area for settlements and other developed land. Land use changes occur in urban and rural areas (2,3). One example, occurred in the Village Pakintelan, Central Java. Pakintelan Village is part of the Garang Hulu River Basin which functions as a protected area for water catchment.

Land use changes significantly affects the cycle and hydrological response, as well as water balance in a catchment area (4-6). One of the impacts of land use change is the emergence of surface runoff which is capable of causing various environmental problems, such as floods, erosion, and sedimentation in downstream areas (7-9).

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Besides land use change, population growth also elevates the groundwater needs. High rate of land use changes can reduce the ability of infiltration, so that the availability of ground water decreases and surface runoff increases (10). Surface runoff occurs when the amount of rainfall that falls exceeds the infiltration rate (11). Surface runoff is part of rainfall that is not absorbed into the soil so that it flows above the surface of the land toward rivers, lakes, or oceans (12).

According to previous researcher (8), surface runoff is influenced by several factors, such as 1) meteorological factors consisting of the type of intensity, duration, and distribution of precipitation, temperature, humidity, solar radiation, wind speed, and air pressure; 2) watershed factors in the form of watershed form, geology, soil type, vegetation and drainage network; and 3) human factors in the watershed. Surface runoff needs to be controlled so as not to cause erosion, flooding, landslides, drought in the dry season, and degradation of groundwater reserves. On the other hand, the availability of groundwater will be balanced and sustainable

Media that can be used to help absorbing water into the ground as well as to minimize environmental damage is called infiltration wells (3). The working principle of infiltration wells is to channel and collect rainwater into holes or wells so that water can have a longer residence time in the ground so that the water can gradually seep into the ground (13). The infiltration well installation is placed at the lowest point in a certain amount of land use in accordance with the runoff discharge generated by each land use so that surface runoff can enter the infiltration well ideally.

This study aims to calculate the surface runoff discharge generated by each land use in the Pakintelan Village. The results of the calculation of surface runoff are then used to determine the estimated number of wells needed to be able to accommodate surface runoff discharge. Success in reducing environmental damage and degradation of groundwater reserves using infiltration wells requires integration between stakeholders and the local community in order to achieve the optimal results.

2. Research Methodology

2.1. Research Location

This research was conducted in the Village of Pakintelan with an area of 3.624 km2. Geographically, Pakintelan Village is located in the upstream area of Kali Garang (river) with its position at 7o09’10.10” South Latitude and 110o39’34.54” East Longitude. With its location in the upstream area, making Pakintelan Village has various geomorphological conditions. Geologically, Pakintelan Village is composed of the Quaternary Kaligetas formation (Qpkg) and is an active fault zone of Kaligarang with structural origin landform units (14, 15). The constituent rocks of the Kaligetas formation consist of dominance of breccia, tuff, tuff sandstone, clay, silt, and conglomerates (16).

Fluvial landform can be seen from the flow pattern of the river in Pakintelan Village which has a rectangular shape that is controlled by the fault structure of Kaligarang. Denudational landform are characterized by the shape of hilly areas and high erosion potential. The type of soil in the study area is Inceptisol with good drainage characteristics, fine texture, cation-exchange capacity (CEC), and very low base saturation. Therefore, it can be concluded that the level of drainage in Pakintelan Village is relatively high and the surface water condition is less stable. The potential for flood and drought disasters is a major problem that is prone to occur at the study site. The condition of Pakintelan Village as shown in Figure 1.

2.2. Data Processing

The data used in this study are land use data, regional morphology, and rainfall. Daily rainfall data measured from the PUSDATARU Central Java Province. Land use data was acquired using aerial photographs by checking field survey validation. While regional morphological data is obtained from processing different height data from contour lines using the ArcGIS program.

The use of detailed spatial data is an superiority in this study. Spatial data acquisition was obtained from aerial photographs with XY resolution of 7 cm and upright resolution (Z) of 50 cm. From this spatial data acquisition the surface runoff discharge is calculated using the rational method with the formula:

$$Q = 0.278\ CxIxA(1)$$

Q is runoff discharge (m3/sec), C is runoff coefficient, I is rainfall intensity (mm/sec), and A is the drainage area (km2) [17-20]. Runoff coefficient value (C) follows to Haryono's classification (21) as shown in Table 1.

Rational methods are widely used to estimate the surface runoff of relatively small watersheds and rural areas scale (18, 22-24) which is very consistent with this research.

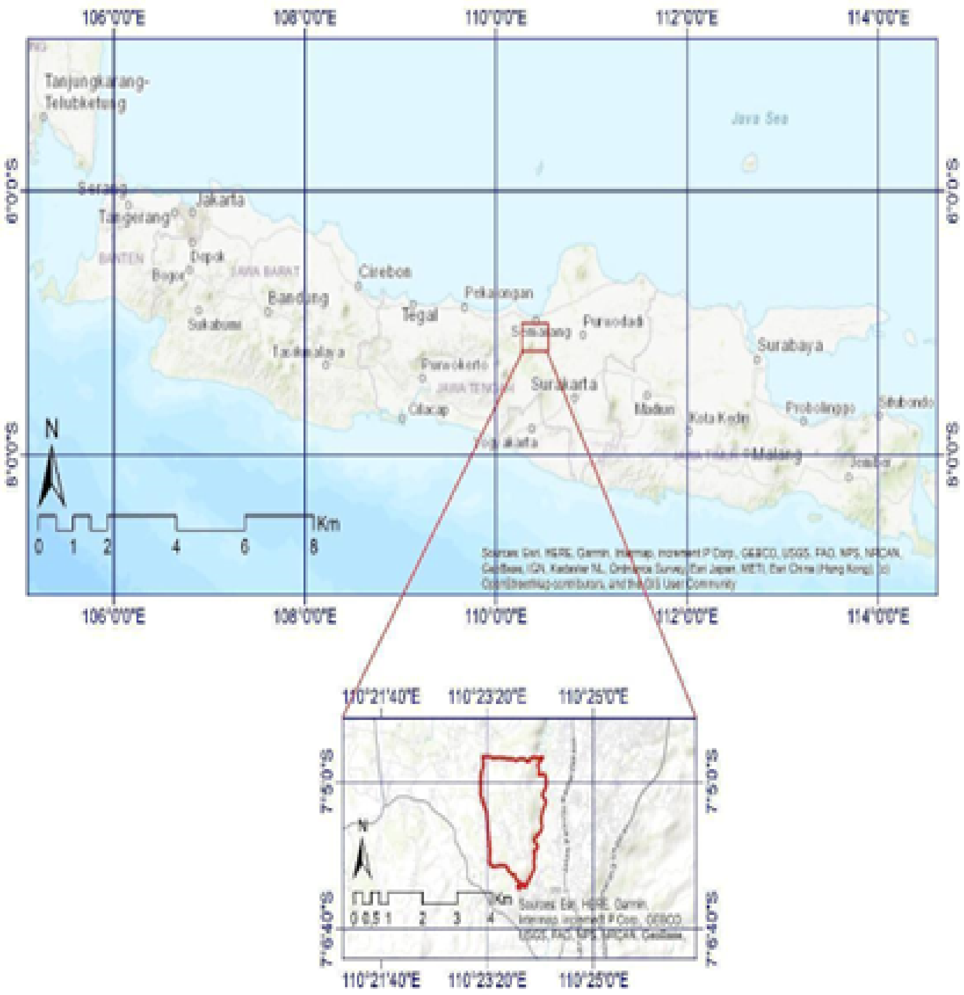

Figure 1: Research location.

TABLE 1: Runoff coefficient (C) in various kinds of land use (Haryono, 1999).

Land use	characteristics	Runoff coefficient (C)
bussinese and shoping center	-	0.90
Industry	full	0.80
moderate to high density of settlement	20 houses/Ha	0.48
	30 houses/Ha	0.55
	40 houses/Ha	0.65
	60 houses/Ha	0.75
paddy field	-	0.15
pond	Flat area	0.20
mixed garden	-	0.10

Concentration time is the time of water to flow from the farthest place to the observation spot or outlet in a catchment area or river basin (17, 21). The concentration time (Tc) in this study was calculated using the Kirpich method (1940) with the following equation (25).

$$Tc = \left(\frac{0,87\ x\ L^2}{1000\ x\ S}\right)^{0,385}$$

As had been explained, Tc is the concentration time in hours. Whereas L2 is the length of the main river in units of km. As the final variable, S is interpreted as the slope of the main channel in units of km. Calculation of rainfall intensity derived from daily rainfall data. Rain intensity in this study was calculated by using the Monobe method (26) with the following equation:

$$I = \frac{R24}{24}\left(\frac{24}{T}\right)^{2/3} (3)$$

The variable used for this Monobe method can be explained that I is interpreted as rain intensity in mm/hour. R24 is maximum daily rainfall in mm. As the last variable T is the length of rain (hours).

3. Research Result and Discussion

Based on the results of land use analysis, Pakintelan Village is an area that is dominated by mixed gardens, while settlements take the second place after mixed gardens. Some areas in the research location also still have bare land. The distribution of land use in Pakintelan Village can be seen in Table 2.

3.1. Surface runoff debit

The results of the calculation of the concentration time (Tc) at the research location were 3.8 hours, while the calculation of the intensity of rain at the research location of 18.62 mm / sec. Furthermore, based on the calculation of surface runoff discharge using the rational method on each land use in the Village of Pakintelan, the total surface runoff discharge is 3.89 m3 / sec. The surface runoff discharge is dominated by mixed garden land use which accounts for 1.39 m3/sec and residential land use which accounts for 1.34 m3/sec. From the calculation results it can be said that the surface runoff discharge is related to the condition of the Pakintelan area which only reaches 3,624 Km2.

Table 2: Land use types in Pakintelan Village.

Land use	Area (Km^2)	Percent (%)
Public facilities	0.023	0.64
Industry	0.049	1.36
Mixed garden	2.688	74.19
Pond	0.001	0.04
Dry field	0.121	3.35
Bare land	0.313	8.65
Field ground	0.009	0.26
Mosque	0.002	0.07
Graveyard	0.007	0.20
Settlement	0.346	9.54
Farm	0.006	0.18
Paddy field	0.052	1.44
School	0.003	0.08
Total	3.624	100.00

Soil at the Pakintelan Village has very low CEC level as well as clay content that is useful for water storage at the research location. This condition threatens the availability of ground water reserves in Pakintelan Village which is also a recharge area. On the other hand, the high potential for surface runoff discharge needs attention as a way to maintain ground water balance. Making infiltration wells in Pakintelan Village is very important to be done, in addition to functioning to reduce surface runoff discharge, making infiltration wells effectively maintain the balance of groundwater reserves (27-28). Calculation of surface runoff discharge based on land use in the Pakintelan Village can be seen in Table 3.

3.2. Considerations on Infiltration Wells

The function of Infiltration wells is to absorb water into the ground and increase groundwater reserves (29). Infiltration well placement was determined based on local topographic aspects and land use that has the highest surface runoff discharge calculated. Land use with the highest runoff discharge is a mixed garden of 1.39 m3 / sec. Mixed garden is the most extensive land use in Pakintelan Village compared to other land uses. In addition, the condition of the cation-exchange capacity (CEC) of the soil is low due to the lack of clay content which makes it difficult to store groundwater in the

Table 3: Surface runoff debit in each land use at the Pakintelan Village.

Land use	Konstanta	Koefisien Aliran (C)	I (mm/dtk)	A (Km^2)	Q (m^3/dtk)
Public facilities	0.278	0.9	18.62	0.023	0.11
Industry	0.278	0.8	18.62	0.049	0.20
Mixed garden	0.278	0.1	18.62	2.688	1.39
Pond	0.278	0.2	18.62	0.001	0.002
Dry field	0.278	0.4	18.62	0.121	0.25
Bare land	0.278	0.3	18.62	0.313	0.49
Field ground	0.278	0.3	18.62	0.009	0.01
Mosque	0.278	0.9	18.62	0.002	0.01
Graveyard	0.278	0.25	18.62	0.007	0.01
Settlement	0.278	0.75	18.62	0.346	1.34
Farm	0.278	0.4	18.62	0.006	0.01
Paddy field	0.278	0.15	18.62	0.052	0.04
School	0.278	0.9	18.62	0.003	0.01
Total				**3.624**	**3.89**

Source: Data Analysis

soil. Infiltration wells are prioritized for locations that have the lowest altitude among one or more land uses. The selection of the location with the lowest elevation aims to make it easier for water to flow into infiltration wells by utilizing the force of gravity. The elevation map of Pakintelan Village is presented in Figure 2.

There are 6 recharge wells based on land use with the highest runoff discharge. Laying of infiltration wells is prioritized between mixed gardens and settlements with the lowest elevation. The location of recharge wells can be seen in Figure 3.

The excess placement of infiltration wells with the highest runoff discharge consideration generated by a land use is to be able to estimate which land use is more in need of recharge wells. So that the planning of making infiltration wells can be further strengthened after knowing the presence of surface runoff debit which is quite large and the duration of infiltration needs to be accelerated so as not to cause inundation, erosion, and other damage. The drawback of placing infiltration wells with this consideration is that it excludes land use that has a surface runoff that is not too large, so it can ignore the possibilities that occur such as the emergence of standing water due to poor drainage systems.

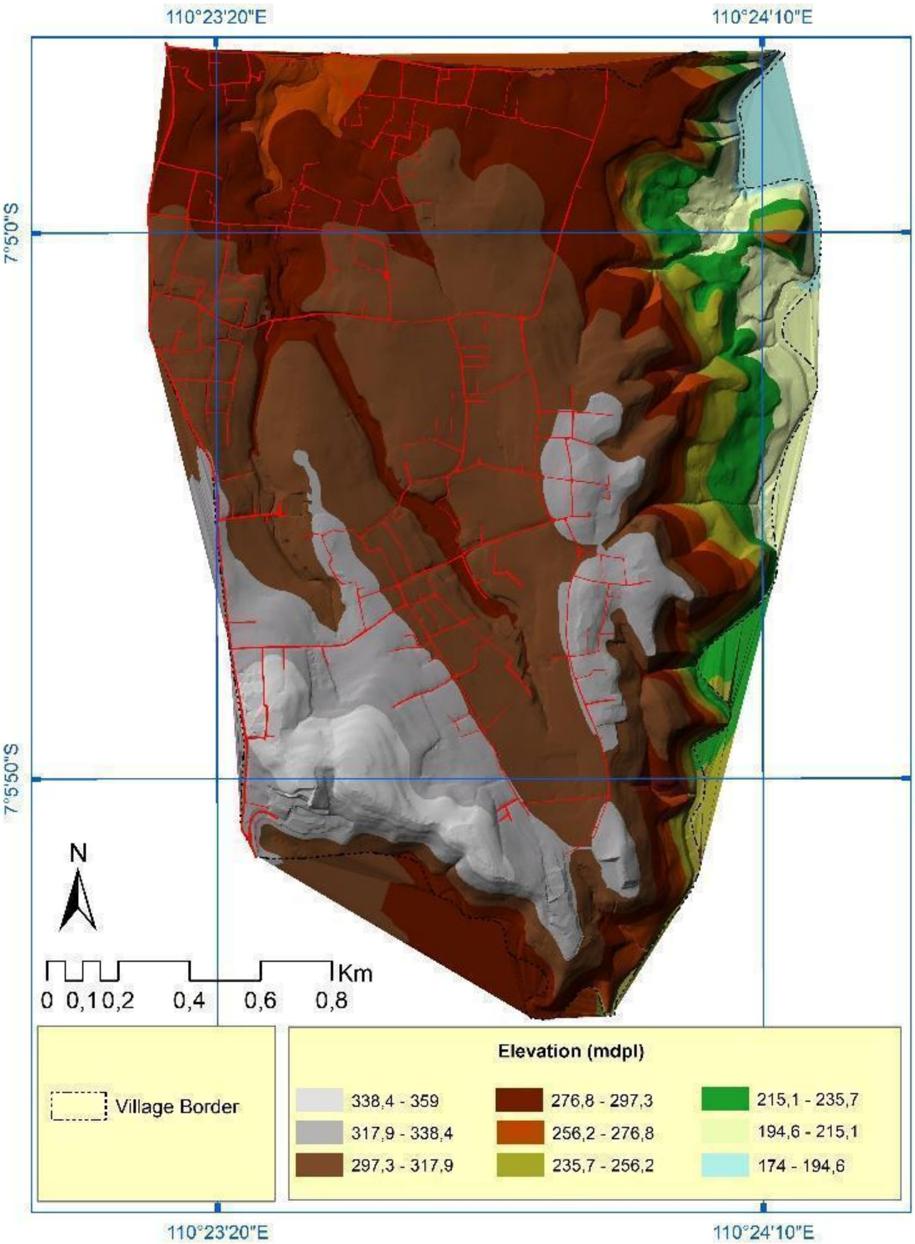

Figure 2: Elevation Map of Pakintelan Village.

4. Conclusion

The results of the runoff calculation using the rational method in the Village of Pakintelan show that mixed gardens and settlements are the two land uses with the most runoff discharge. Thus the priority of placement of infiltration wells needs to be aligned with the two land uses. This attention becomes important when the Pakintelan Village has a low CEC and its position is in the recharge area.

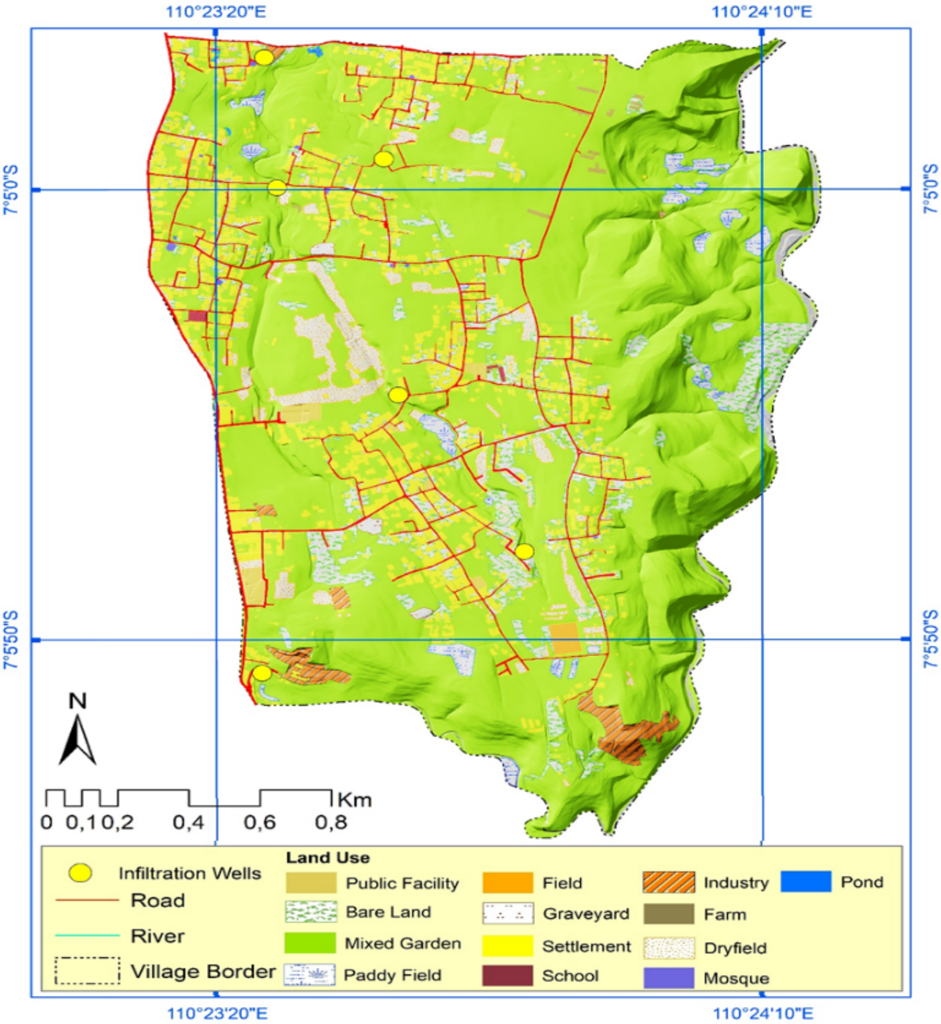

Figure 3: Recommendation of Infiltration wells placement at the Pakintelan Village.

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