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Assesing Water Infiltration Potential to Suport Sustainable Community Development

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Abstract

The availability of clean water is a basic need often unmet in several areas of Indonesia, including Sukagalih Village in Jonggol District, Bogor Regency, West Java. The village faces difficulty accessing clean water due to population growth, climate change, and a lack of water management infrastructure. The community service initiative aims to help address these issues by identifying available water sources and mapping the potential recharge areas in Jonggol District. The methods used include primary data collection through field observations and interviews with the community, direct measurement of water discharge at the source using a flow meter to determine the flow rate at the water source, while the determination of the groundwater recharge area is based on four parameters: rainfall; slope; land use; and soil type. Based on the results of activities and analysis, four water sources are located in Dusun 2 and Dusun 3 with a discharge of 0.126 liters/second, which does not yet meet the community's raw water needs. Based on the analysis of the potential of the groundwater recharge area, Sukagalih village has a high potential for groundwater recharge areas based on rainfall data, soil, land use, and slope gradient.

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INTRODUCTION

Water scarcity remains a significant issue in many parts of the world, including Indonesia. Sukagalih Village in Jonggol faces challenges in obtaining clean water (Sky, 2023; Suryana, 2023; Zakaria, 2023). This area is located in Bogor Regency, West Java, and has a relatively large population yet faces limited access to clean water. Several factors contribute to water scarcity in Sukagalih Village, including rapid population growth, extreme climate change, and inadequate water management infrastructure (Lestari & Suprapto, 2022). This situation has made it difficult for the community to access clean water for their daily needs. Therefore, there is a need for a study on the water requirements of the population and the identification of potential water sources to meet those needs.

Mapping water sources can facilitate better water resource management planning in the future (Fauziah *et al.*, 2024). This community service activity is also relevant to the current situation, highlighting the importance of sustainable natural resource management (Marni, 2019). This community service activity aims to support environmental preservation and sustainable natural resource management in Sukagalih Village by analyzing water needs and mapping water sources. For these reasons, the initiative seeks to analyze the community's water requirements and map the potential water source areas in Sukagalih Village to ensure adequate clean water availability for its residents. Sukagalih Village is one of the largest villages in Jonggol District, consisting of six hamlets. As of 2020, the population of Sukagalih Village reached 4,254, with an annual growth projection of 1.5%. The village includes Sukagalih village, Cibadak village, Sukamulya village, Jatimulya village, Margahayu village, and Tirtamulya village. The two hamlets that will be the focus of this community service initiative are Sukagalih Village, which has the largest area and population compared to the others.

Sukagalih village covers an area of 450 hectares with a population of 2,159. Located in the northern part of Sukagalih Village, at an elevation of 200 to 400

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meters above sea level. Additionally, several small springs are along the slopes of the mountains to the southwest of both hamlets. However, the water flow from these springs tends to diminish during the dry season. To address the issue of sustainable water availability, it is essential to identify potential new water sources and map recharge areas, considering factors such as land area, population, topography, rainfall, and soil types in Dusun Sukagalih and Cibadak. The increasing population is likely to heighten the demand for clean water, while the availability of clean water remains heavily reliant on rivers and existing springs. Several rivers in Sukagalih Village have experienced a decline in water quality due to human activities, such as waste disposal. Additionally, climate change is believed to influence fluctuations in rainfall in the region.

Effective water resource management requires a comprehensive and integrated approach that emphasizes the interconnections between water, energy, and food in the context of sustainable development. This nexus approach is particularly relevant for Sukagalih Village, given the community's dependence on water resources for domestic use and agriculture (Purnomo *et al*., 2021)

The Bogor Environmental Agency data indicates an average rainfall decrease of 5-10% over the past decade in Jonggol District. This condition could significantly impact groundwater availability. The community in Sukagalih Village still relies on water sources to stock up for the dry season. However, the capacity of these water sources is deemed insufficient to meet both current and future needs. Therefore, it is necessary to identify potential new water sources and map recharge areas to ensure sustainable water availability for the community.

This community service activity is expected to benefit water resource management planning in Sukagalih Village. As described, Sukagalih faces challenges in meeting its water needs. Population growth and climate change are likely to exacerbate water availability in the future, while the existing water sources are not sustainably reliable.

Thus, a detailed analysis of the community's water needs and the potential new water sources for long-term use is essential. Mapping recharge areas is also crucial to identify potential locations for groundwater resources (Wibowo, 2006; Alfadli *et al*., 2016). This aligns with the Sustainable Development Goals to provide access to clean water and adequate sanitation for all. This community service activity aims to provide a comprehensive overview of the water availability conditions and potential water sources in Sukagalih Village, serving as a foundation for more integrated and sustainable water resource management planning in the future. The results of this community service initiative are expected to benefit local government in policy-making related to clean water availability for the residents of Sukagalih Village.

MATERIALS AND METHODS

This community service activity employs a quantitative approach through descriptive quantitative studies and direct field surveys, utilizing interviews and measurements. This initiative is located in Sukagalih Village, Jonggol District, Bogor Regency, West Java. The project adopts a multi-criteria approach to analyze the potential recharge areas, using scoring and weighting methods (Gunawan *et al*., 2016; Permana *et al*., 2024; Nurrohman & Nugroho, 2014; Kholis & Rendra, 2022). The analysis focuses on the two main hamlets: Sukagalih and Cibadak. Primary data collection techniques include field observations and interviews with key informants. Observations are conducted to assess the physical conditions of the community service area and existing water sources, while interviews aim to gather information on the community's water needs and usage. Secondary data collection techniques involve documentation studies and demographic analysis. The secondary data includes topographic maps, rainfall data, soil types, and socio-economic information of the community.

This community service project utilizes a quantitative approach through descriptive studies conducted in Sukagalih Village, Jonggol District, Bogor Regency. Primary data collection involves field observations and interviews to examine the area's conditions, water sources, and community water needs and usage information. Secondary data, such as topographic maps, rainfall, soil types, and socio-economic data, are gathered through documentation studies.

Domestic water needs analysis refers to the standards set by the Ministry of Public Works and Housing (Kementerian PUPR), while potential water sources are identified through flow rate analysis, recharge well depth, and water quality assessments. Mapping of recharge areas analyzes factors such as rainfall, slope, soil type, and land use using Geographic Information Systems (GIS). The outcomes of this community service activity are expected to provide a comprehensive overview of water availability for sustainable water resource management planning in Sukagalih Village. The flow chart can be seen in Fig. 1.

RESULTS AND DISCUSSION

Water Availability Discharge

Analyzing environmental carrying capacity is crucial for the development of sustainable settlements. Widodo demonstrated the importance of this analysis in the context of urban Yogyakarta,

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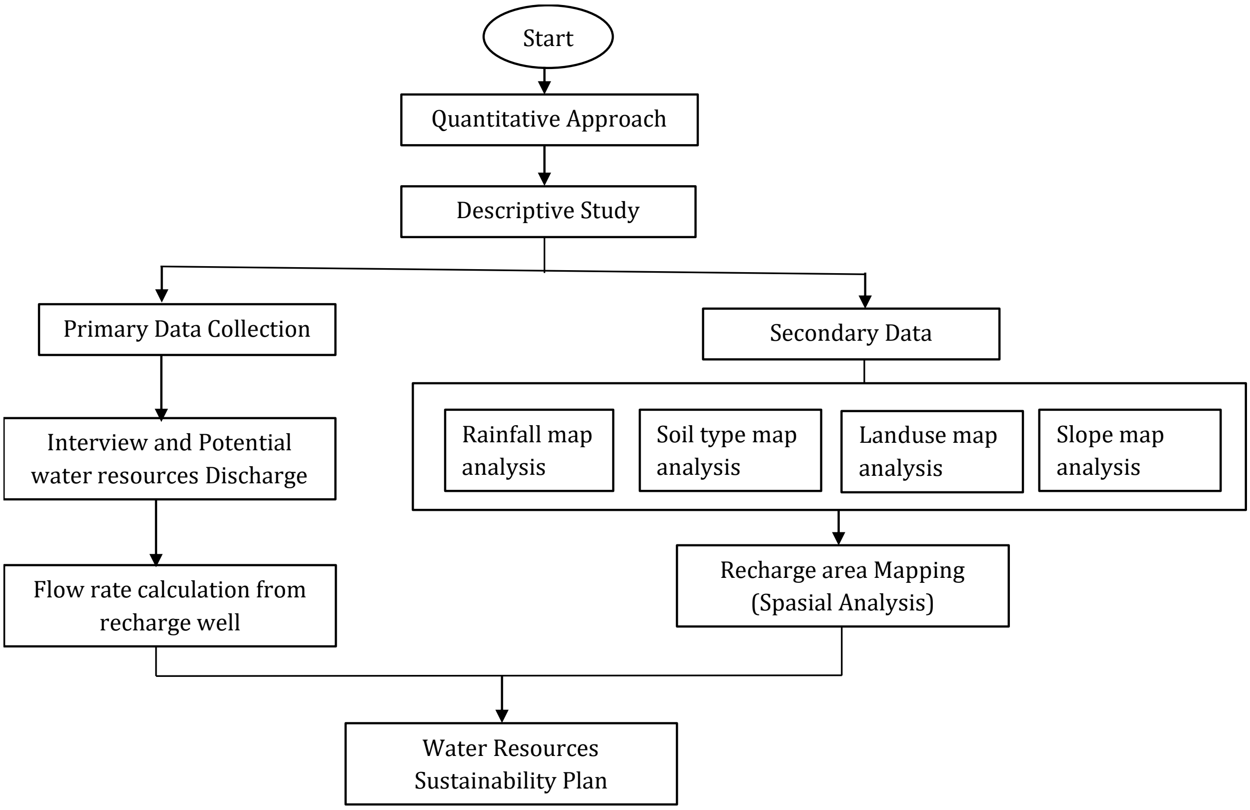

Fig. 1. Flow chart diagram

which can be adapted for Sukagalih Village by taking into account local characteristics (Widodo *et al*., 2015). Sukagalih Village has four main water sources: Water Source 1, Water Source 2, Water Source 3, and Water Source 4. Water Source 1 is located in Dusun Cibadak at coordinates 6°39'32.34" S and 106°38'46.12" E. This source is a spring with a drip flow. The flow rate measurement shows an average of 0.015538 liters/second. Water Source 2 is situated at the border of Dusun Sukagalih, with coordinates 6°39'21.96" S and 106°38'39.12" E. This source is a small stream flowing from the mountain slope, with an average flow rate of 0.025538 liters/second. Water Source 3 is located downstream of Dusun Sukagalih at coordinates 6°39'15.24" S and 106°38'30.48" E. Water Source 4, located at coordinates 6°39'32.34" S and 106°38'46.12" E, is found in Dusun 3. This source is a small river with the highest flow rate among the four water sources, measuring 0.05538 liters/second (Kepmenkimpraswil Nomor: 403/KPTS/M/2002 Tentang Pedoman Teknis Pembangunan Rumah Sederhana Sehat (Rs Sehat).

The four water sources identified in the field survey in Sukagalih Village are crucial freshwater sources for the local community. However, further analysis indicates that the flow rates of these three sources are relatively low. Specifically, Water Source 1 produces only drips, suggesting that its capacity may be insufficient to meet the community's water needs, especially if the village population continues to grow. This is a serious concern, as rapid population growth could place greater pressure on these limited water resources. For more information regarding the field survey activities and the conditions of the water sources, refer to Fig. 2 for the coordinates before conducting the survey. The condition of Water Source 1 can be seen in Fig. 3, the condition of Water Source 2 in Fig. 4, the condition of Water Source 3 in Fig. 5, and the condition of Water Source 4 in Fig. 6.

The calculation of water availability flow rates in Sukagalih Village was conducted for the three main water sources: Water Source 1, Water Source 2, and Water Source 3. For example, the flow rate of Water Source 1 was calculated based on the volume of water flowing over a specific time period. The measured water volume during the assessment was 350 ml, and the time taken to discharge this volume was 22.23 seconds.

To calculate the flow rate, the water volume is divided by the measurement time. Therefore, 350 ml divided by 22.23 seconds results in a 15.74 ml/second flow rate. In other words, the flow rate of Water Source 1 is 15.74 ml/second. The same calculation was performed for Water Sources 2 and 3 to

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determine the flow rates of each water source. These flow rate results were then analyzed to assess whether they could meet the water needs of the Sukagalih Village community.

Fig. 2. Implementation of coordination

Fig. 3. Water source 1

Fig. 4. Water source 2

Fig. 5. Water source 3

Fig. 6. Water source 4

Based on the analysis of parameters, grouping was then conducted to obtain a distribution map of potential recharge areas. This will be explained further in the next section. The calculations for water availability flow rates in Sukagalih Village, Jonggol, are as follows (Kemenkes RI, 1990).

Water source 1 calculated :
V = 350 ml
t = 22,23 second
Q = V/t
 = 350/22,23
 = 15,74 ml/second

Thematic Maps for Each Parameter

The process of creating thematic maps refers to the four key parameters that determine recharge areas: land use, slope, rainfall, and soil type. Mapping the recharge areas in Sukagalih Village can utilize the same method as in Langsat Permai Village, considering land use, slope, rainfall, and soil type (Karmadi & Wibawa, 2022; As'aria *et al.*, 2017;

Nurrohman & Nugroho, 2014). Here are the results of the analysis and thematic maps for each parameter:

1. Land Use
   The land in Jonggol District is utilized for urban areas, agriculture, and forests. Based on the scoring provided, agricultural land received the highest score due to its high porosity. The thematic map indicates that the southern region is a potential recharge area.
2. Slope
   The majority of the area has slopes greater than 15-40 degrees. This condition is assessed to have high recharge potential because water can infiltrate more quickly on sloped terrain.
3. Rainfall
   Jonggol District receives an average annual rainfall of 2,000-3,000 mm. Water recharge is estimated to be high in areas with rainfall exceeding 2,500 mm per year.
4. Soil Type
   Regosol and Mediterranean soils are the dominant soil types. Both of these soil types have high water infiltration rates, making them potential recharge areas(Alves *et al*., 2024)

The calculation of water availability flow rates in Sukagalih Village was conducted for the three main water sources: Water Source 1, Water Source 2, and Water Source 3. For example, the flow rate of Water Source 1 was determined based on the volume of water flowing over a specific period. The measured water volume during the assessment was 350 ml, and the time taken to discharge this volume was 22.23 seconds.

The water volume is divided by the measurement time to calculate the flow rate. Thus, 350 ml divided by 22.23 seconds results in a 15.74 ml/second flow rate. In other words, the flow rate of Water Source 1 is 15.74 ml/second. The same calculation was performed for Water Sources 2 and 3 to determine the flow rates of each source. The results of these flow rate calculations were then analyzed to assess whether they could meet the water needs of the Sukagalih Village community.

Domestic Water Needs

The analysis of domestic water needs is based on the population and domestic water requirements according to the Regulation of the Minister of Public Works and Housing No. 5 of 2016. According to BPS data, the population of Sukagalih Village in 2021 is 4,345 people. Water Source 1 has a water volume of 350 ml, and the time required to fill this volume is 22.23 seconds. The formula for calculating the flow rate is volume divided by time. Therefore, the flow rate for Water Source 1 is calculated as follows:

Volume of water (V) = 350 ml
Filling time (t) = 22.23 seconds
Flow rate formula (Q) = V/t
Substituting the values into the formula:
Q = 350 ml / 22.23 seconds
Q = 15.74 ml/second

Table 1. Water availability flow rates in Sukagalih Village, Jonggol

No	Water Source	Volume (ml)	Time (second)	Debit (l/dtk)
1	Spring 1	350	22.23	0.016
2	Spring 2	350	6.32	0.055
3	Spring 3	350	6.42	0.055
				0.126

The flow rates of each water source in Sukagalih Village are as follows: Water Source 1 has a flow rate of 0.01574 l/second, Water Source 2 has a flow rate of 0.05538 l/second, and Water Source 3 has a flow rate of 0.05452 l/second (Table 1). Among these three sources, the highest flow rate is from water source 2. When summed, the total flow rate from the three sources is 0.125641 l/second, equivalent to 10,855.414 liters per day.

In addition to these three sources, Water Source 4 is located in Dusun 3 of Sukagalih Village (Fig. 6). The flow rate of this source cannot be determined because it consists of calm surface water; however, this source is available year-round, both in the dry and rainy seasons, and is a crucial supply for meeting the raw water needs in Dusun 3. To calculate the water availability from this river, the following calculation is performed:

Water flow velocity (V) = 66 m/second
Cross-sectional area (A) = 5 m x 8 m = 40 m²
The formula for calculating flow rate is:
Q = V x A
Substituting the values:
Q = 66 m/second x 40 m²
Q = 2,640 m³/second
If converted to liters per day, the flow rate of the river is: 228,096,000,000 liters/day

Thus, the flow rate of this river is significantly greater than the total flow rates from the three water sources in Sukagalih Village.

Factors Determining Recharge Areas

Several factors determine the potential of recharge areas, namely rainfall, soil type, slope, and land use. The average rainfall in Sukagalih Village is between 2,000-3,000 mm per year. Areas receiving rainfall of ≥2,500 mm per year are considered potential for recharge. The majority of the soil in Sukagalih Village consists of Regosol and Mediterranean types. These soil types have fine grains and high relevant structure, allowing them to accumulate water and enhance infiltration.

Most of the area has a slope of 15-30 degrees. This slope is considered to have a high potential for

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recharge, as gravity can accelerate water movement into the ground. Agricultural land, including rice fields and gardens, is assessed to have the most potential due to its more open soil pores for infiltration (Hulu *et al*., 2023; Suprapti *et al*., 2024). Based on the analysis of these four factors, the southern area of Sukagalih Village, which has high rainfall, good recharge soil type, a slope of 15-30 degrees, and widespread agricultural land, shows potential to be a groundwater recharge area. This region is suitable for further exploration as a potential groundwater source for future clean water needs. Mapping based on a Geographic Information System (GIS) was conducted to further analyze the potential of recharge areas. Thematic maps were created for each factor and then processed into a distribution map, indicating high classification values for recharge potential.

Based on the thematic map of rainfall, most of Sukagalih Village falls into class 2 (2,500-3,000 mm/year). For soil type, the majority consists of Regosol and Mediterranean, which fall into classes 1 and 2. In terms of slope, parts of the southwest and south are classified into classes 1 and 2 with a slope of 15-30 degrees. Regarding land use, the southern and eastern areas are rice fields and agricultural land, categorized as class 2.

All thematic maps were overlaid to obtain the final map of potential recharge area distribution. The GIS processing results indicate that the southern area of Sukagalih Village has a high classification value, making it a very promising area for groundwater recharge.

Table 2. Land use scoring results

Landuse Classification	Area (Ha)	Infiltration	Weight	Score
Settlement	119.00	Small	1	3
Plantation	82.77	Large	4	12
Rice Field	527.80	Small	1	3
Bare Land/Deforested	6.44	Medium	3	9
Dryland/Farm	63.74	Quite Small	2	6

Based on the scoring in Table 2, the land use map has been generated (Fig. 7). This map visually represents the distribution of different land uses in the area, highlighting the potential for groundwater recharge based on the assigned scores. Areas with higher scores, such as agricultural land and forested regions, indicate greater water infiltration and recharge potential, while urban and bare land areas show lower potential. The map is a valuable tool for planning and managing water resources in Sukagalih Village. Table 2 and Fig. 7 provide information about land use in the mapped area. Visually, it can be seen that irrigated agricultural land (light green) dominates the land cover, followed by natural forests (dark green). Residential or settlement areas (red) are also scattered across several locations.

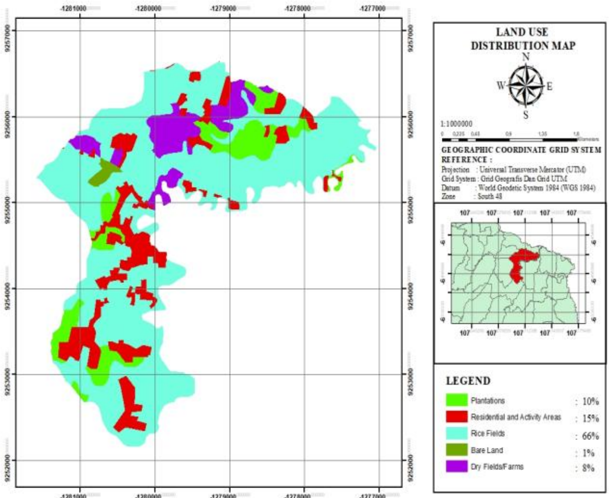

Fig. 7. Land use map of Jonggol District

Additionally, there are identified vacant or unused lands (purple), although they are in smaller quantities. Non-irrigated agricultural land (yellow) is also visible but in limited amounts. It indicates a diversity of land use in the area, reflecting various human activities such as agriculture, housing, and local land conditions. This depiction shows significant variation in land cover, as represented by the table and map. Next, we consider the slope parameter. The slope is an important factor influencing the potential of recharge areas. Steeper slopes affect the movement of water into the ground.

Based on the analysis of Land Resource (SDL) in Jonggol District, there are four classifications of slope that serve as references:

1. 0-8% (gentle): Low recharge potential because water will flow slowly on the surface.
2. 8-15% (moderate): Moderate recharge potential because the slope allows water to move underground.
3. 15-30% (steep): High recharge potential because gravity accelerates water infiltration into deeper soil layers.
4. >30% (very steep): Very high recharge potential but prone to erosion, which can strip soil layers and reduce recharge capacity.

Based on the digital elevation model (DEM) map, most of Sukagalih Village falls into the 15-30% slope category. This indicates good recharge potential in the area. Meanwhile, steep slopes greater than 30% are only found in mountainous regions, making their extent relatively small. Thus, the slope parameter positively contributes to the designation of recharge areas in Sukagalih Village.

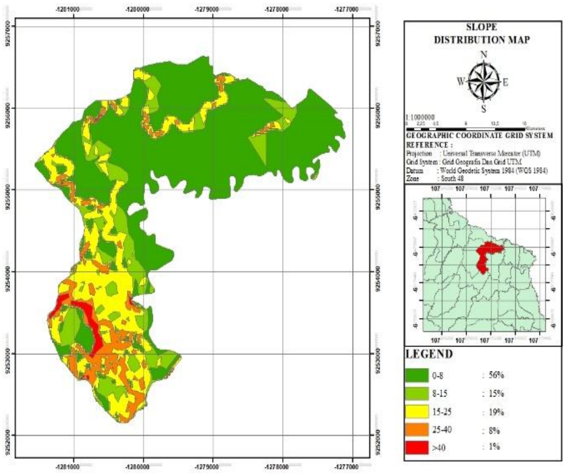

Fig. 8. Slope map of Jonggol

Fig. 8 shows the slope analysis results in Sukagalih Village, indicating a variation in slope levels in the area. Most of the region has a low slope of 0-8%, marked in green, which is ideally suited for settlement and agriculture due to its low erosion risk and good soil stability. There are also areas with a moderate slope of 8-15%, marked in yellow, as well as high slopes of 15-25% and 25-40%, marked in light and dark brown, which require special attention in their use through soil conservation techniques to prevent erosion. Areas with very steep slopes greater than 40%, marked in red, pose a significant risk of erosion and landslides, making them unsuitable for development without adequate erosion control; it is better to designate these as protected forests. Based on this analysis, it is concluded that the slope of the land in Sukagalih Village varies throughout the area.

Rainfall is also an important factor influencing the potential for recharge areas. The higher the rainfall in a region, the greater the likelihood of water infiltration into the soil.

Based on the average monthly rainfall data over the past 10 years in Sukagalih Village, the following information has been obtained:

1. The average annual rainfall ranges from 2,000 to 3,000 mm.
2. The wet months are December to February, with an average rainfall of over 200 mm per month.
3. The dry months are August to September, with rainfall less than 100 mm per month.

This range of annual rainfall is then classified as follows:

1. <2,000 mm/year = Low recharge potential
2. 2,000-2,500 mm/year = Moderate recharge potential
3. 2,500-3,000 mm/year = High recharge potential
4. >3,000 mm/year = Very high recharge potential.

The complete details can be seen in Table 3.

Table 3. Rainfall infiltration scoring

No	Infiltration Rainfall (mm/year)	Area (Ha)	Description	Weight	Score
1	2,500 - 3,000	1.87	Moderate	3	12
2	3,000 - 3,500	749.63	Quite Large	4	16

Fig. 9 shows the results of the average annual rainfall range analysis in the area. The red-colored areas indicate that most of the region receives rainfall ranging from 3,000 to 3,500 mm per year, according to the legend on the left side of the screen. This information indicates that the majority of the area experiences very high levels of rainfall.

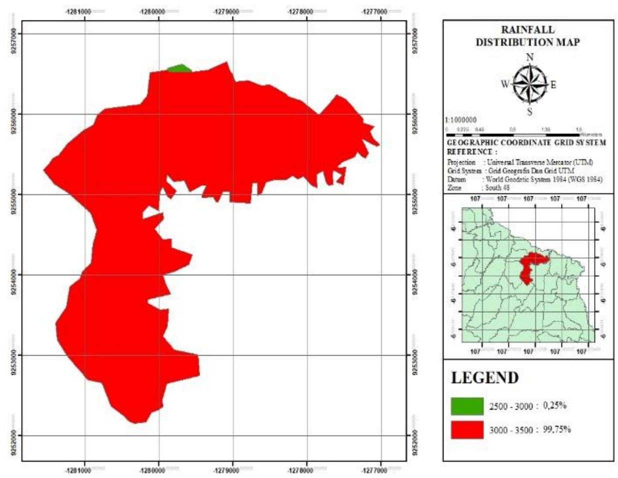

Fig. 9. Rainfall map of Jonggol District

In addition, areas marked in yellow indicate rainfall ranging from 2,500 to 3,000 mm per year. Details in the legend indicate that regions within this rainfall range also have high groundwater recharge potential due to the elevated average annual rainfall in the area.

The soil types are classified into three classes:

1. Chromic Vertisols, which have high water infiltration (recharge) capacity, are rated 3. With a weight of 3, the weighting score is 9.
2. District Nitrosols, which have moderate infiltration capacity, are rated 2. With a weight of 3, the weighting score is 6.
3. Orthic Acrisols, which have low infiltration capacity, are rated 1. With a weight of 1, the weighting score is 3.

In other words, this explanation details the classification of soil types based on their infiltration capacity (high, moderate, low), which are then assigned scores and weights to calculate the total weighting score (Table 4) for analyzing the soil type parameter, the results of which can be seen in Fig. 10.

Table 4. Soil type scoring results

No	Soil Type	Area (Ha)	*Infiltration*	Weight	Score
1	*Chromic Vertisols*	111.12	High	3	9
2	*Orthic Acrisols*	429.50	Moderate	2	6
3	*District Nitrosol*	211.88	Low	1	3

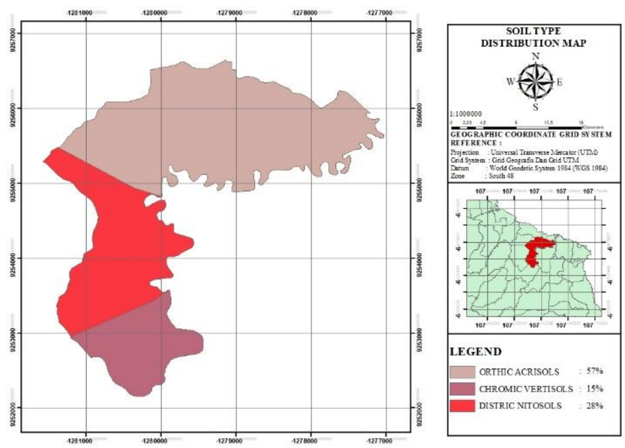

Fig. 10. Soil Map

The map shows the variation in the distribution of three soil types in the area, where Orthic Acrisols, the center by District Nitrosols, and the south by Chromic Vertisols, dominate the north. This indicates a diversity of soil conditions that may be influenced by factors such as topography, climate, and land use(Wibowo, 2006):

1. Chromic Vertisols have a high clay texture, making them expansive and contractive depending on water content. They are dark in color due to their high mineral and organic matter content.
2. District Nitrosols are fertile and rich in nitrogen, which is important for plant growth. Their good structure allows for effective air and water circulation.
3. Orthic Acrisols are found in high rainfall areas with low organic content and are acidic, making them less fertile without fertilization. Their structure is less stable and prone to erosion.

In other words, the map illustrates the variation of soil types in the area, while the descriptions detail the characteristics of each soil type according to its classification.

Distribution of Groundwater Recharge Areas

High-resolution global datasets provide valuable information about flood plains on Earth. Although this dataset is global in scale, the methodologies used can be adapted to identify and map potential recharge areas around Sukagalih Village more accurately (Syifaurrohman *et al*., 2018; Arabameri *et al*., 2019; Li et al., 2023; Nasution *et al*., 2020). The majority of the Jonggol sub-district has very high groundwater recharge conditions, accounting for approximately 62.58% of the total area. This condition aligns with the region's high elevation and high rainfall characteristics. Additionally, about 30.86% of the area falls into the high category, while only 6.56% has moderate recharge potential. No areas with low or very low recharge conditions were found, indicating that the overall recharge potential in Jonggol sub-district is generally very good to high, with less than 10% having moderate recharge potential (Fig. 11).

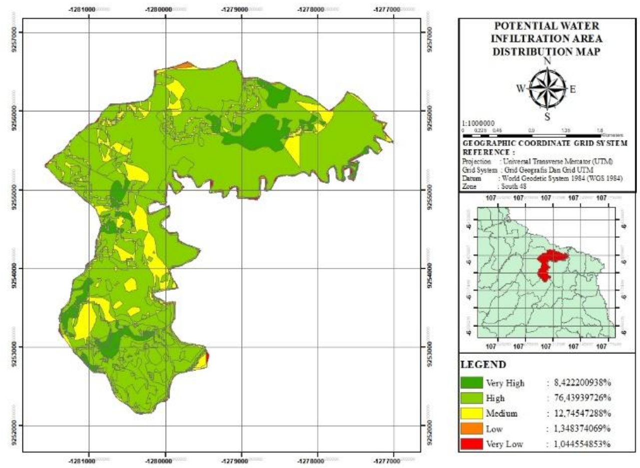

Fig. 11. Potential water infiltration area in Sukagalih Village

Based on the overlay results for the distribution of groundwater recharge conditions in Jonggol sub-district, the recharge potential specifically for Sukagalih Village can be analyzed. Overall, Sukagalih Village is located in an area with high groundwater recharge potential, although a small portion in the northern part has moderate recharge potential. With this high recharge potential, the area can effectively store and absorb water, indicating that Sukagalih Village has valuable groundwater sources to meet the domestic water needs of its residents.

Moreover, the analysis of water availability shows that the existing water sources are currently insufficient to meet demand. Given the high recharge potential, this area is hoped to serve as another potential water source that can be utilized through groundwater management technologies, such as infiltration wells. Additionally, solar-powered irrigation systems represent an alternative agricultural water pump that can be developed. The use of solar-powered water pumps can help address water shortages in rain-fed fields by designing and creating portable solar water pumps.

CONCLUSION

Based on the analysis of environmental carrying capacity and water source availability in Sukagalih Village, it can be concluded that meeting the community's raw water needs is a significant challenge. Although there are four main water sources, namely Source 1, Source 2, Source 3, and Source 4, the measured flow rates from these sources are still relatively low, particularly for Source 1, which can only produce a flow of 15.74 ml/second. With the continuous growth of the village's population, the demand for clean water is expected to rise in the future. However, the existing water sources cannot meet this demand optimally. This shortage highlights the need for more effective management of available water resources and the exploration and utilization of groundwater recharge areas to increase groundwater availability for community needs. According to the recharge potential distribution map, several areas with high potential can be developed for environmentally friendly recharge wells, such as utilizing solar-powered water pumps. These efforts are expected not only to ensure the availability of sufficient clean water for the community but also to support sustainable settlement development in Sukagalih Village. As a follow-up, improvements in the management of existing water resources are necessary, including the development and utilization of more environmentally friendly recharge systems to address the limitations of water sources and meet the growing demand for clean water in the future. The success of this sustainable water management will also contribute to the village's better development, making it more resilient to future climate change challenges.

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