Identification of the critical level of water recharge area in the Citarik subwatershed

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Abstract. The Citarik sub-watershed is part of the upstream Citarum watershed which has an area of 22,637.83 ha. This sub-watershed has upstream in the Buru Kareumbi Masigit Forest Conservation Area in Sumedang Regency and empties into the Citarum River in the Bandung Regency area. Land-use changes due to increasing socio-economic activities of the community have a reduction in water recharge areas in this region. Potential problems that can occur due to these conditions are the occurrence of groundwater scarcity, and flooding. This study is intended to determine the critical level of water recharge areas in the watershed. The research method uses descriptive analysis methods that refer to the classification of natural infiltration potential. Important parameters in the classification of natural infiltration include parameters of soil type, land cover, rainfall, and slope. The analysis showed that the critical level of water catchment in the Citarik sub-watershed with good conditions of 5,802.78 ha (25.63%), natural normal conditions 2,291.1 ha (10.12%), rather critical conditions 11,735.3 ha (51.84%), conditions began to be critical of 1,892.91 ha (8.36%), and critical conditions were 915.73 ha (4.05%). Region are dominate of the water recharge conditions in the Citarik watershed with a rather critical level. Most of the areas with these conditions are settlements, so it is necessary to refill groundwater using infiltration well and bioretention ponds technology.

1. Introduction
A watershed is a region where a natural system of complex hydrological, biophysical, socio-economic and complex community culture. In watershed systems, these processes are interrelated and have an impact on the quality, quantity, and continuity of water resources. A common problem in watersheds in Indonesia is the uncontrolled change in land use due to an increase in population. The more population, the greater the need for living space. This has caused changes in forest land and agricultural land into settlements. These land-use changes cause a reduction in water catchment areas in a watershed area and increase surface runoff water. The logical consequence of the increase in surface runoff water is the occurrence of flooding during the rainy season and lack of water in the dry season because water is not successfully stored as much and as long as possible in one watershed system. [1]

This problem is indicated by the Citarik sub-watershed which is one of the upstream parts of the Citarum watershed. The Citarik watershed has a total area of 22,637.83 ha. This sub-watershed has an upstream area in the Kareumbi Masigit Forest Conservation Area of Sumedang Regency and empties into the Citarum River in the Bandung Regency area. Land use conditions in the 2003–2008 range saw an increase in the number of settlements in the Citarik sub-watershed area from 18.7% to 18.8% and an increase in paddy fields from 19.4% to 29.9%. in addition, the decrease in a hydrological the function
that occurred in the Citarik sub-watershed area was marked by an increase in runaway water coefficient from 0.22 in 2000 to 0.42 in 2007 [2]. The Jatinangor and Rancaekek subdistricts, which are included in the Citarik sub-watershed area, are two areas that have a high potential for land-use change due to the development of the two regions into educational and industrial areas. The high number of inhabitants living in this area causes a decrease in groundwater level due to uncontrolled groundwater extraction to meet the needs of daily life [3]. Potential problems from these conditions are the scarcity of clean water due to excess water withdrawal and reduced water catchment areas due to land-use change. For this reason, it is necessary to identify the condition of water catchment areas to find out the current conditions of water catchment areas in the Citarik Sub-watershed area. Some parameters that affect water catchment areas are soil type, rainfall, slope, and land use [4].

2. Material and methods

2.1. Materials
The material used in this study is a map of the Citarik sub-watershed area, data on land characteristics, soil type, rainfall, land use and slope in the Citarik sub-watershed area. In addition, in this study spatial data processing software is used to do the stages of spatial analysis, including map making, determining the area of infiltration areas and map overlays.

2.2. Methods
The research method used is descriptive analysis, which describes the parameters of water catchment areas in the Citarik Sub-watershed, Sumedang-Bandung-Garut Regency which are then analyzed using a Geographic Information System (GIS) by overlaying or overlapping maps and classified based on the critical criterion of catchment areas water according to the Ministry of Forestry (2009). Data analysis and overlay processes are carried out using the ArcMap 10.3 applications. Data analysis was performed to determine the potential infiltration and actual infiltration using the overlay method. According to Regulation of the Minister of Forestry of the Republic of Indonesia number 32 of 2009 concerning Procedures for the Preparation of Forest and Land Rehabilitation Technical Plan (RTkRLH-DAS), infiltration potential is influenced by slope, rainfall and soil factors. While the actual infiltration is influenced by land use. The four factors are then presented in the form of a map. The following are the weights for each parameter.

| Table 1. Slope scoring. |
|-------------------------|
| No | Slope (%) | Description | Score | Notation |
|---|-----------|-------------|-------|---------|
| 1 | <8 | Flat | 5 | a |
| 2 | 8–15 | Sloping | 4 | b |
| 3 | 15–25 | Wavy | 3 | c |
| 4 | 25–40 | Step | 2 | d |
| 5 | >40 | Very Step | 1 | e |

The slope in table 1. Is the slope of the land relative to the flat plane. Expressed in units of percent or degree. The slope factor is used to determining water catchment areas because it affects the infiltration of water into the soil. The slope is divided into five categories based on the slope interval from the flat to very steep. The highest score island with a flat area with a slope of less than 8%.

| Table 2. Scoring of soil types. |
|-------------------------------|
| No | Soil Type | Infiltration | Score | Notation |
|---|-----------|-------------|-------|---------|
| 1 | Black Andosol | Big | 5 | a |
| 2 | Brown Andosol | Rather Big | 4 | b |
| 3 | Regosol | normal | 3 | c |
| 4 | Latosol | Rather Small | 2 | d |
| 5 | Aluvial | Small | 1 | e |
Table 2. Shows the classification of soil type scoring. Soil types consist of black andosol, brown andosol, regosol, latosol, and alluvial [5]. The soil type with the highest score is black andosol because it has large infiltration characteristics.

| No | Rain Infiltration (mm/day) | Infiltration   | Score | Notation |
|----|----------------------------|----------------|-------|----------|
| 1  | < 2500                     | Low            | 5     | a        |
| 2  | 2500–3500                  | Moderate       | 4     | b        |
| 3  | 3500–4500                  | Rather heavy   | 3     | c        |
| 4  | 4500–5500                  | Heavy          | 2     | d        |
| 5  | >5500                      | Very Heavy     | 1     | e        |

Rainfall scoring is determined based on the infiltration rainfall factor obtained from the equation below:

\[ RD = 0.01 \times P \times Hh \] (1)

Information:
RD = Factor of infiltration rain
P = Annual rainfall
Hh = Number of rainy days every year

Table 3. Rainfall scoring.

| No | Classification of infiltration | Land Cover                        | Score | Notation |
|----|--------------------------------|-----------------------------------|-------|----------|
| 1  | Big                            | Dense Forest                      | 5     | A        |
| 2  | Rather Big                     | Production Forest, Plantation     | 4     | B        |
| 3  | Medium                         | Bush, meadow                      | 3     | C        |
| 4  | Rather Small                   | Field, dry land, Hortikultura     | 2     | D        |
| 5  | Small                          | settlement, the yard, rice field  | 1     | E        |

Actual infiltration rates in table 4. Determined based on the type of land cover vegetation. Land cover vegetation types affect infiltration through three forms, including root and pores enlarging soil permeability, vegetation holding run-off and vegetation reducing the amount of percolation water through transpiration. After scoring the values and assessing the parameters mentioned above, the water catchment conditions can be classified by comparing natural infiltration values with actual infiltration values. The criteria used are as follows as presented in table 5.

Table 5. Classification of the criticality of watersheds for actual infiltration.

| No | Criteria           | Note                                                                 |
|----|--------------------|                                                                     |
| 1  | Good               | If the actual infiltration value is greater than the natural infiltration value. |
| 2  | Normal Natural     | If the actual infiltration value is the same or fixed as the natural infiltration value. |
| 3  | Getting Critical   | If the actual infiltration value has dropped one level from the natural infiltration value. |
| 4  | Rather Critical    | If the actual infiltration value has dropped one level from the natural infiltration value. |
| 5  | Critical           | If the actual infiltration value has dropped three levels from the natural infiltration value. |
| 6  | Very Critical      | If the actual infiltration value changes from very large to very small. |

(Source: [6])
3. Result and discussion

Determination of water catchment areas is done by analyzing infiltration in the Citarik Sub-watershed based on four parameters that affect the ability of soil infiltration, such as slope parameters, soil type, rainfall distribution, and land use. These four parameters are used as a basis for assessing catchment areas presented in the form of a thematic map for overlay analysis.

3.1. Slope

The slope is a topographic factor that affects the infiltration of water into the ground due to differences in surface run off velocity at each level of land slope. In this study, the slope level is divided into five classes as shown in table 1.

Based on the analysis conducted, the slope distribution in the Citarik sub-watershed is 44.81% included in the class of slope < 8% categorized as flat. The area of the flat category reaches 10,142.66 ha. 17.19% or an area of 3889.81 ha of the Citarik watershed sub-area included in the sloping slate (8–15%). Meanwhile, for the category of undulating slope (15–25%) the area of the area reaches 3835.47 ha or 16.95%. The percentage of steep slopes (25–40%) reached 16.28% with an area of 3685.86 ha. The characteristics of areas with very steep conditions (> 40%) in the Citarik sub-watershed are only 1.079.99 ha (4.77%). The distribution of slope conditions in the Citarik sub-watershed is shown in figure 1.

![Figure 1. Sloping slope map on the Citarik Watershed.](image)

Based on the parameters of the slope, the Citarik Sub-watershed area is dominated by the slope class < 8% or flat. Judging from the conditions, the Citarik watershed sub-watershed has a fairly good water catchment. The slope has an influence on the ability of the infiltration of an area. High infiltration rates occur in a land with slopes < 8%. Areas with small, flat, other slope slopes are areas that have good infiltration characteristics, because water that falls above the ground surface does not directly become surface runoff, but the water has time to hold and soak into the ground [7]. While the area with a slope level of 15–25% has a small infiltration rate because the area locate water transportation, so that water cannot be infiltrated maximally into the ground [8].

3.2. Soil type

Soil type affects the infiltration rate due to differences in the texture of each soil type. The lower the value of the mass density (bulk density) of the soil, the greater the pore volume of the soil, and the more soil crumbs, the greater the infiltration rate. Soil with rough texture has a high infiltration capacity [7].
Components in the type of soil that have a major influence on the ability of infiltration are soil texture, soil porosity and soil organic matter [9]. Based on the analysis of the soil types shown in figure 2. The Citarik sub-watershed area of 61.4% has a latosols type of land with an area of 13.898.7 ha, the second most type of soil found in this region is alluvial soil type with an are of 5.892.90 ha (26.03%). The smallest distribution of soil types is andosol soil with an area of 2.846.21 ha or around 12.57% of the total area of the Citarik sub-watershed area. Based on table 2, latosols soil types have a score of 2, alluvial soil types by 1 and andosol soil types by 5. So that, based on soil type parameters, water infiltration in the Citarik Sub-watershed is rather small. This is because the type of soil that dominates in the Citarik Sub-watershed area is latosols. Latosols soil type is clayey textured with a proportion of sand fraction 20–45%, dust 15–53%, and clay 27–40%. A high proportion of clay in latosols soil types causes the ability of infiltration to be relatively low [10]. The results of the analysis of the distribution of soil types in the Citarik sub-watershed are shown in figure 2.

![Map of Soil Type in the Citarik Sub-watershed](image)

**Figure 2.** Map of soil types in the Citarik Sub-watershed.

### 3.3. Rainfall

The rain factor used in this study is the infiltration rain factor (RD) with the assumption that potentially, infiltration will be greater for rain with a longer period of time. The rainfall data used is the last 10 years data on nine rainfall stations which are included in the Citarik sub-watershed area. Analysis of rainfall data then made into Polygon Thissen calculations.

**Table 6.** RD values and Percentage of area of rainfall distribution.

| No | Post Name | RD    | Area (ha) | Percentage |
|----|-----------|-------|-----------|------------|
| 1  | Cicalengka| 3,758.80 | 2,670.5165 | 11.80      |
| 2  | Paseh     | 3,633.38 | 2,918.6924 | 12.89      |
| 3  | Dampit    | 3,587.01 | 6,491.9591 | 28.68      |
| 4  | Pamulihan | 4,705.27 | 539.7601  | 2.38       |
| 5  | Jatiroke  | 1,794.57 | 728.5231  | 3.22       |
| 6  | Tanjungsari| 2,855.40 | 682.2478  | 3.01       |
| 7  | Rancakelk| 2,546.50 | 1,707.0409 | 7.54       |
| 8  | Sapan     | 2,433.35 | 406.0527  | 1.79       |
| 9  | Ciluluk   | 2,461.89 | 6,493.0322 | 28.68      |
| Total |          |        | 22,637.8248 | 100        |
Based on the data in table 6. The highest infiltration rain value is in the area included in the rain recovery station coverage. The value of rainfall infiltration (RD) in the region reached 4,705.27. While the smallest infiltration rain value is the coverage of the Jatiroke rainfall station at 1,794.57. Based on the average infiltration rainfall value at the rain stations in the Citarik sub-watershed area, these sub-watersheds have a moderate recharge rate.

3.4. Land use
The type of land use of the Citarik Sub-watershed was obtained from the 2017 land use map from the Citarum-Ciliwung BPDAS, Bogor. Land use is one of the parameters that give effect to the actual infiltration in the watershed area. Land cover in the area. Research includes forests, gardens, bushes, fields, rice fields and developed land. Based on the analysis of land use maps in the Citarik Sub-watershed, the largest land use is rice fields with an area of 9,747.38 ha (41.18%) and settlements of 3,867.17 ha (16.34%). The distribution of land use in the Citarik sub-watershed area is shown in figure 3 below.

![Map of Land-use in the Citarik Subwatershed](image)

**Figure 3.** Land use map in the Citarik watershed.

Based on the results of the analysis, it can be stated that the ability of infiltration in the Citarik Sub-watershed is relatively small because it is dominated by paddy fields. The ability of small infiltration in paddy fields is because generally, paddy fields must always be in flooded conditions so that the soil in the paddy fields is already in saturated condition, therefore in paddy fields, it is no longer able to absorb water into the soil. Inundation that occurs in the area causes water to continuously enter the soil, when the soil is saturated, the rate of water absorption will be moister [11]. In areas where vegetation is overgrown with a high level of infiltration caused by plant roots, it can increase soil porosity. In addition, vegetation enlarges the level of water storage in an area so that the infiltration rate becomes large [11]. The low level of infiltration in the built-up area is caused by closed pores on the surface of the soil so that water cannot seep and turn into surface runoff [12].

3.5. Natural Infiltration Scoring
Natural infiltration is determined by the summing of scoring parameters of the slope, soil type, and rainfall distribution in the Citarik sub-watershed area. Parameters in determining natural infiltration are parameters that cannot be influenced by human activity. The scoring of the three parameters for the condition of natural infiltration in the Citarik sub-watershed is shown in table 7.
Table 7. Scoring conditions for natural infiltration in the Citarik sub-watershed.

| Slope Parameters sloping | Soil Parameters | Rain Parameter | Total Score | Natural Condition Infiltration |
|--------------------------|-----------------|----------------|-------------|-------------------------------|
| 40–100% (Very step)      | Latosol         | 2              | 2           | 5                             |
| 25–40% (Step)            | Latosol         | 2              | 3           | 7                             |
| 0–8% (Flat)              | Aluvial         | 1              | 3           | 9                             |
| 8–15% (Slovin)           | Andosol         | 5              | 4           | 13                            |

Based on the analysis conducted, the Citarik Sub-watershed area is dominated by the potential for natural infiltration in the medium category with an area of 15,249.97 ha (67.61%). This happens because the region is in a slope that is dominated flat to gentle slope and moderate average infiltration rainfall. Regional distribution based on the level of natural infiltration is shown in figure 4.

Figure 4. Map of the distribution of natural infiltration in the Citarik Sub-watershed.

The natural infiltration condition in the very small category in the Citarik sub-watershed area is only 10.82 ha or around 0.05% of the whole area. Based on natural infiltration maps, it shows that some parts of the Citarik Sub-watershed are unable to absorb water well enough. The southern region of the Citarik watershed has a greater infiltration coefficient than the northern region. Besides that, the southern region has a smaller runoff efficiency than the northern region, this shows that more water is infiltrated in this region [13].

3.6. Critical condition of watershed areas

The condition of water catchment areas is classified by comparing the value of natural infiltration with actual infiltration. The natural infiltration value is obtained from the overlay of the slope map, soil type, and rainfall distribution. While the actual infiltration value is obtained from the land use map. The extent of land criticality in the Citarik sub-watershed is shown in table 8.
Table 8. Critical condition of watersheds in the Citarik Sub-watershed.

| No | Class             | Area (ha)       | Percentage (%) |
|----|-------------------|-----------------|----------------|
| 1  | Good              | 5,996.3588      | 25.40          |
| 2  | Naturally Normal  | 2,484.6824      | 10.53          |
| 3  | Rather Critical   | 11,928.8817     | 50.53          |
| 4  | Start to Critical | 2,086.4928      | 8.84           |
| 5  | Critical          | 1,109.3100      | 4.70           |
|    | Total             | 23,605.73       | 100            |

Based on table 8, the critical condition of the Citarik Sub-watershed catchment area is 25.40% included in either class category. The area in the good category reaches 5,996.36 ha. The overall distribution of the level of criticality of the Citarik sub-watershed area is shown in figure 5 below.

Figure 5. Map of critical water catchment areas in the Citarik Sub-watershed.

Based on the results of the analysis carried out, the largest extent of critical water catchment areas in the Citarik Sub-watershed is including a rather critical condition with a percentage reaching 50.53% of the total area. The total area in this rather critical condition reached 11,928.89 ha. Areas with good land criticality are in forest areas. This can occur because the comparison between natural infiltrations in these regions is moderate and actual infiltration conditions are small on average. Distribution of land use in areas with a rather critical condition is paddy fields and settlements. Forest areas are dominated by plants with large roots compared to cultivation plants that have shallow roots. This root system affects the penetrating power of the soil. Plants with hard roots are able to break through to the deep soil layer so that it forms soil aggregates and produces soil cavities that can increase the level of water infiltration into the soil [14].

4. Conclusion

A total of 25.63% of the water catchment conditions in the Citarik Sub-watershed are in good condition, 51.84% are in a rather critical condition, 8.36% are starting to be critical, and 4.05% are at a critical level. Based on the description, in general, the condition of water catchment areas in the Citarik sub-watershed is at a rather critical level which reaches 51.84% of the total area. The total area with a rather critical condition reaches 11,735.3 ha.
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