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Spatial Analysis of Water Infiltration Criticality Distribution in the Northern Bandung Area (KBU)

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Abstract
This study aims to map water infiltration criticality in the Northern Bandung Area and identify areas with critical and very critical levels to support spatial planning and sustainable groundwater management. Infiltration criticality was analyzed using a spatial overlay of four parameters: soil type, rainfall, land use, and slope. Each parameter was scored based on infiltration potential, weighted according to influence, multiplied by its weight, and summed to produce a total infiltration value. Results were classified into six categories—Good, Naturally Normal, Beginning to Critical, Moderately Critical, Critical, and Very Critical—using Sturges' formula for class intervals. Spatial analysis revealed variation in infiltration criticality across Northern Bandung Area. Moderately Critical areas dominate, covering 125.43 km² (32.57%), followed by Beginning to Critical (82.36 km², 21.41%) and Naturally Normal (79.52 km², 20.66%). Good areas are limited (19.07 km², 4.95%), while Critical and Very Critical zones cover 88.67 km² (20.42%). Regionally, Critical and Very Critical areas occupy 13.05 km² (14%) in Kabupaten Bandung, 30.37 km² (12%) in Kabupaten Bandung Barat, 21.75 km² (66%) in Kota Bandung, and 11.26 km² (64%) in Kota Cimahi. This study applies an established weighted overlay method to the entire Northern Bandung Area, extending previous research limited to subdistricts, and provides a comprehensive spatial overview of critical infiltration zones for regional planning and groundwater management.

Keywords: Northern Bandung, Spatial Analysis, Urbanization, Water Infiltration

1. Introduction

A water infiltration area is a region that functions to absorb surface water into the saturated zone, thereby forming subsurface flow that moves toward lower areas (KLHK-RI, 2022). In spatial planning, water infiltration areas play a crucial role in ensuring the availability of groundwater, which serves as an essential water source on Earth (Ministry of Agrarian Affairs and Spatial Planning/National Land Agency, 2021). he reduction or loss of infiltration areas may lead to several adverse impacts, including the decline of groundwater reserves, an increased risk of flooding, and the overall deterioration of environmental quality. Consequently, the extent of water infiltration areas continues to decrease due to various factors, such as urbanization, land-use change, deforestation, and uncontrolled land management practices (Khasanah et al., 2022).

As one of the strategic provincial regions, the Northern Bandung Area (Kawasan Bandung Utara, KBU)—which encompasses parts of Bandung Regency, Bandung City, Cimahi City, and West Bandung Regency—plays a vital role in supporting sustainability and maintaining environmental balance within the Bandung Basin (Afdillah & Aprilana, 2021). This role is reinforced by the West Java Provincial Regulation No. 2 of 2016, which stipulates that one of the primary objectives of managing the KBU is to preserve its hydrological function as a water catchment, infiltration, and flow area for the downstream regions. In line with this, the Directorate of Geology and Environmental Planning reports that approximately 60% of the total 108 million m^3 of groundwater supplying the Bandung Basin originates from the KBU, highlighting its significance as a critical water catchment zone for the sustainability of water resources in the area (Wijayakusuma, 2023). Furthermore, in accordance with Law No. 26 of 2007 on Spatial Planning, any regional development within the KBU must prioritize the protection of environmentally strategic areas and prevent hydrological degradation resulting from uncontrolled land-use conversion.

In Cimenyan District, a land-use conversion of approximately 211 hectares (15.45%) of infiltration areas into built-up areas occurred between 2011 and 2016, particularly in Cipageran and Citeureup Villages. This conversion was driven by the increasing demand for housing and the low level of public awareness regarding the importance of infiltration areas (Wijayakusuma, 2023). The consequences of this transformation include not only heightened flood and drought risks but also a decline in groundwater quality, as observed in Lembang Village and Ciumbuleuit Subdistrict (West Java Environmental Agency, 2023).

The decline in water infiltration areas across several parts of the Northern Bandung Area represents an urgent issue that requires spatial and quantitative analysis. Therefore, this study aims to identify the spatial distribution of areas with varying levels of water infiltration criticality within the Northern Bandung Area. The findings are expected to serve as a guideline for policymakers in planning more sustainable land use and preserving the ecological functions of the KBU as a key water infiltration zone, thereby supporting the long-term sustainability of water resources within the Bandung Basin.

2. Research Method

The main variable analyzed in this study was the water infiltration criticality, which was determined based on four key biophysical parameters influencing infiltration capacity, namely soil type, rainfall, land use, and slope gradient. Data used in this study were obtained from both primary and secondary sources. Primary data consisted of field observations to validate the physical characteristics of the study area and land-use surveys, while secondary data were collected from various official institutions, including soil type maps from the Geospatial Information Agency (Badan Informasi Geospasial, BIG), rainfall data from the Meteorological, Climatological, and Geophysical Agency (BMKG), land-use maps from the Regional Development Planning Agencies (Bappeda) of West Java Province and respective municipalities or regencies, and slope data from the Food and Agriculture Organization (FAO) and related agencies. Additional information was obtained from literature reviews and relevant scientific publications to support the analysis.

The assessment of water infiltration criticalitys was conducted through spatial analysis using a weighted scoring method, in which each parameter was assigned a score and weight based on its relative influence on infiltration capacity (Aprilana & Oktavian, 2021). The scoring and weighting system followed the Regulation of the Minister of Forestry of the Republic of Indonesia

No. P.32/MENHUT-II/2009 concerning the Technical Guidelines for Watershed Rehabilitation Planning (RTkRLH-DAS).

Table 1. Soil Type Scoring

Soil Type	Infiltration	Score
Black Andosol	High	5
Brown Andosol	Moderately High	4
Regosol	Moderate	3
Latosol	Moderately Low	2
Alluvial	Low	1

Source: Regulation of the Minister of Forestry of the Republic of Indonesia (No. P.32/MENHUT-II/2009)

Table 2. Rainfall Scoring

Annual Rainfall (mm/year)	Infiltration	Score
< 2,500	Low	1
2,500 – 3,500	Moderately Low	2
3,500 – 4,500	Moderate High	3
4,500 – 5,500	High	4
> 5,500	Very High	5

Source: Regulation of the Minister of Forestry of the Republic of Indonesia (No. P.32/MENHUT-II/2009)

Table 3. Land Use Scoring

Land Use	Infiltration	Score
Dense forest	Very Ggood	5
Production forest, plantation	Good	4
Shrubland, grassland	Moderate	3
Dry field, horticulture	Poor	2
Settlement, rice field, yard	Very Poor	1

Source: Regulation of the Minister of Forestry of the Republic of Indonesia (No. P.32/MENHUT-II/2009)

Table 4. Slope Gradient Scoring

Slope (%)	Classification	Infiltration	Score
0 – 8	Flat	Very Good	5
8 – 15	Gentle	Good	4
15 – 25	Moderately Steep	Moderate	3
25 – 40	Steep	Poor	2
> 40	Very Steep	Very Poor	1

Source: Regulation of the Minister of Forestry of the Republic of Indonesia (No. P.32/MENHUT-II/2009)

Table 5. Parameter Weights for Water Infiltration

Parameter	Weight
Soil Type	4
Rainfall	3
Land Use	2
Slope Gradient	1

Source: Regulation of the Minister of Forestry of the Republic of Indonesia (No. P.32/MENHUT-II/2009)

The classification of water infiltration criticalitys was obtained through the overlay and weighted summation of the four parameters (soil type, rainfall, slope gradient, and land use). The total score infiltration for each location was calculated using the following formula adapted from Hastono and Dwi (2012) in Adibah (2013).

$$\textbf{Total Value} = (Kb \times Kp) + (Pb \times Pp) + (Sb \times Sp) + (Lb \times Lp)$$

Where Kb is the soil type score, Kp is the soil type weight, Pb is the rainfall score, Pp is the rainfall weight, Sb is the land-use score, Sp is the land-use weight, Lb is the slope score, and Lp is the slope weight. The composite scores obtained from this calculation were then used to classify the study area into six categories of infiltration criticality, namely Good, Naturally Normal, Beginning to Critical, Moderately Critical, Critical, and Very Critical. The determination of class intervals was carried out using Sturges' formula, which defines the range of each infiltration criticality class (Hendriana, 2013 in Aprilana & Oktavian, 2021):

$$Ki = \frac{(Xt - Xr)}{k}$$

Where Ki is the class interval, Xt is the highest total value, Xr is the lowest total value, and k is the number of infiltration criticality classes. The resulting classification map served as the basis for identifying spatial variations in the criticality of water infiltration zones within the Northern Bandung Area.

3. Results and Discussions

The analysis of water infiltration criticality in the Northern Bandung Area (Kawasan Bandung Utara, KBU) was conducted based on four biophysical parameters: soil type, rainfall, land use, and slope gradient. Each parameter contributed differently to the infiltration potential of the region, influencing the overall classification of water infiltration criticality.

Soil Type in the Nortehrn Bandung Area

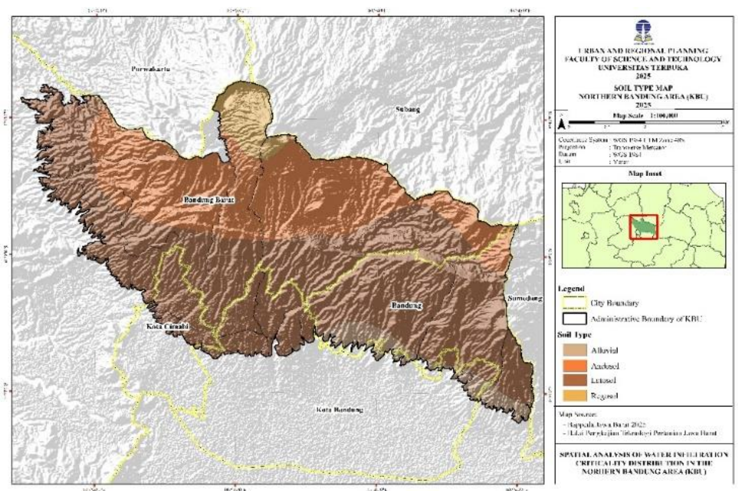

Figure 1. Soil type map of the Northern Bandung Area

Table 6. Soil Type Scoring

Soil Type	Weight	Score	Area (km²)
Brown Andosol	4	4	120.9
Regosol		3	15.3
Latosol		2	233.3
Alluvial		1	15.73
Total			**385.23**

Source: Author's analysis, 2025

The results show that Latosol is the dominant soil type in the KBU, covering 233.3 km² (60.5%), followed by Andosol (31.4%), Regosol (4.0%), and Alluvial (4.1%). Latosols typically have fine to moderate textures with high clay content, which restricts percolation and reduces infiltration potential. Conversely, Andosols—formed from volcanic ash—exhibit higher porosity and permeability, enabling more effective infiltration and water retention.

These characteristics indicate that the inherent soil conditions of the KBU limit infiltration capacity in a large proportion of the area, particularly in the Latosol-dominated zones. The spatial distribution of these soil types aligns with the volcanic geomorphology of northern Bandung, where weathered volcanic materials evolve into less permeable soils over time.

This finding aligns with Simelane et al. (2024), who demonstrated that fine-textured soils such as Latosols and Alluvials impede infiltration compared to coarser-textured Andosols. It implies that soil texture plays a decisive role in shaping hydrological response, especially under changing land use conditions.

Rainfall in the Northern Bandung Area

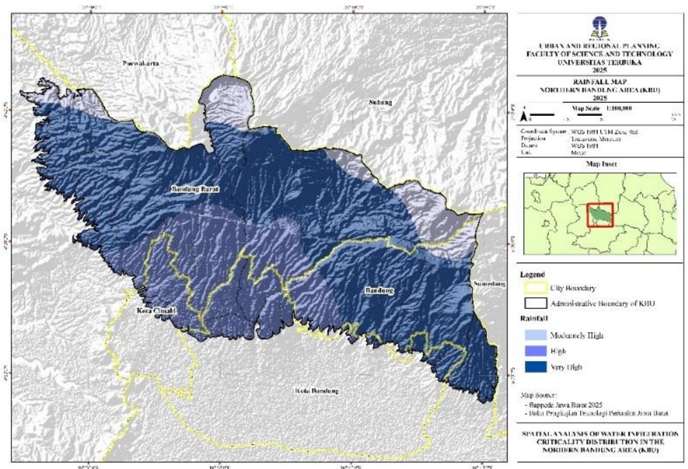

Figure 2. Rainfall map of the Northern Bandung Area

Table 7. Rainfall Scoring

Annual Rainfall (mm/year)	Weight	Score	Area (km²)
3,500 – 4,500		3	103.55
4,500 – 5,500	3	4	241.56
> 5,500		5	40.12
Total			**385.23**

Source: Author's analysis, 2025

Rainfall across the KBU is generally high, with more than 60% of the region receiving 4,500–5,500 mm/year and another 10% experiencing rainfall above 5,500 mm/year. Such precipitation intensity theoretically enhances groundwater recharge and infiltration potential. However, rainfall alone is not a guarantee of high infiltration, as it depends strongly on surface characteristics and soil permeability. In areas with impermeable surfaces or compacted soils, intense rainfall tends to increase surface runoff rather than infiltration, thereby contributing to flood risks and reduced groundwater recharge.

Thus, while rainfall acts as a positive hydrological driver, its effect in the KBU is mitigated by the dominance of fine-textured soils and the expansion of built-up land, especially in the southern parts adjacent to urban Bandung.

Land Use in the Northern Bandung Area

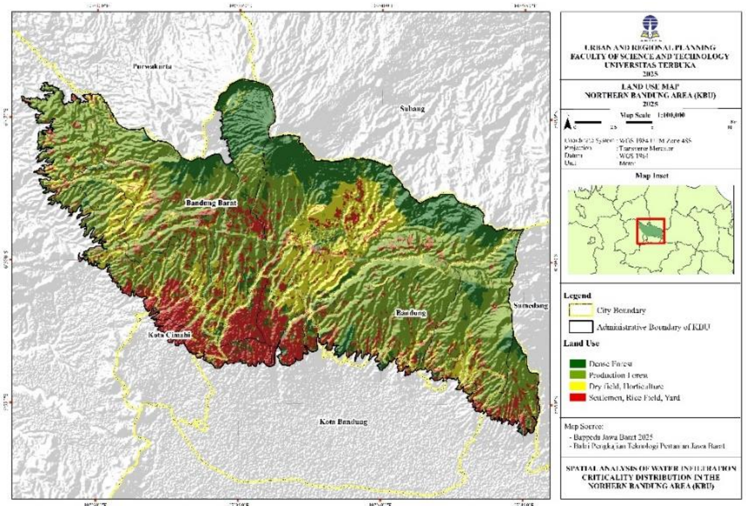

Figure 3. Land use map of the Northern Bandung Area

Table 8. Land Use Scoring

Land Use	Weight	Score	Area (km²)
Dense Forest	2	5	63.28
Production Forest		4	199.96
Dry Field, Horticulture		2	56.26
Settlement, Rice Field, Yard		1	66
Total			**385.23**

Source: Author's analysis, 2025

Land use in the KBU is dominated by production forests and plantations (51.9%), followed by dense forests (16.4%). These vegetated areas generally exhibit high infiltration potential due to extensive root systems that improve soil structure and increase porosity. However, 17.1% of the land is already occupied by settlements, rice fields, and yards, which significantly reduce infiltration and promote runoff.

Urban expansion in areas such as Lembang, Cimenyan, and Parongpong has led to progressive land-use conversion from vegetated to impervious surfaces, resulting in declining infiltration capacity. This transition is consistent with research by Khasanah et al. (2022), who found that urban growth in the KBU has caused significant degradation of infiltration zones and disrupted local hydrological equilibrium.

Vegetated areas thus play a critical role as ecological buffers, mitigating runoff and promoting infiltration. Maintaining and restoring such land uses is vital for the hydrological sustainability of the Bandung Basin, especially as the KBU functions as a regional water catchment area.

Slope Gradient in the Northern Bandung Area

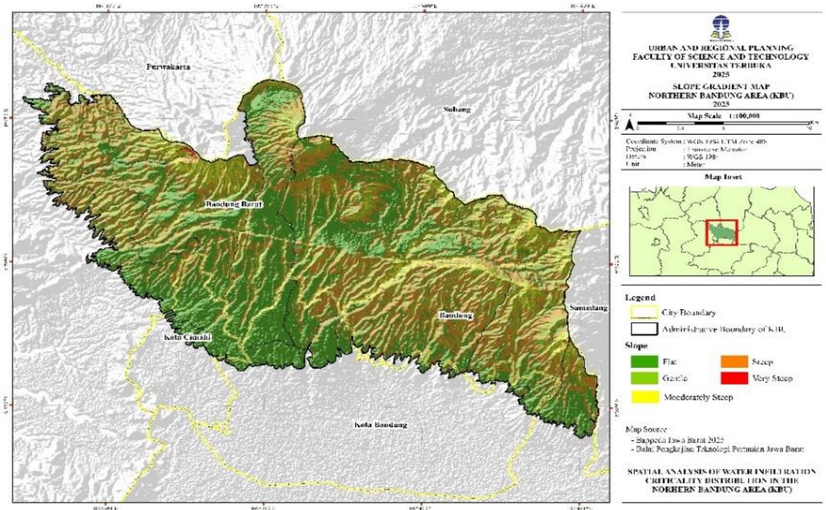

Figure 4. Slope gradient map of the Northern Bandung Area

Table 9. Slope Gradient Scoring

Slope (%)	Weight	Score	Area (km²)
0 – 8		5	186.63
8 – 15		4	121.73
15 – 25	1	3	59.21
25 – 40		2	15.92
> 40		1	2.24
Total			**385.23**

Source: Author's analysis, 2025

The slope gradient map reveals that flat to gently sloping areas (0–15%) dominate the KBU, comprising 80% of the total area. These conditions are generally favorable for infiltration because water moves more slowly across flat surfaces, allowing more time for absorption. However, in urbanized zones with impervious cover, this potential is often lost, transforming infiltration zones into areas of rapid surface runoff and localized flooding.

In contrast, steep areas (>25%) exhibit reduced infiltration not because of soil impermeability but due to gravity-induced runoff acceleration, which limits water residence time on the surface. Pasquier et al. (2022) reported similar dynamics in Los Angeles, where topography interacts with land cover to determine infiltration efficiency.

Hence, the KBU's topography inherently supports infiltration, but this advantage is being undermined by urban sprawl and poor land management practices, particularly in downstream transition zones between steep forested and flat urban areas.

Spatial Distribution of Infiltration Critcality

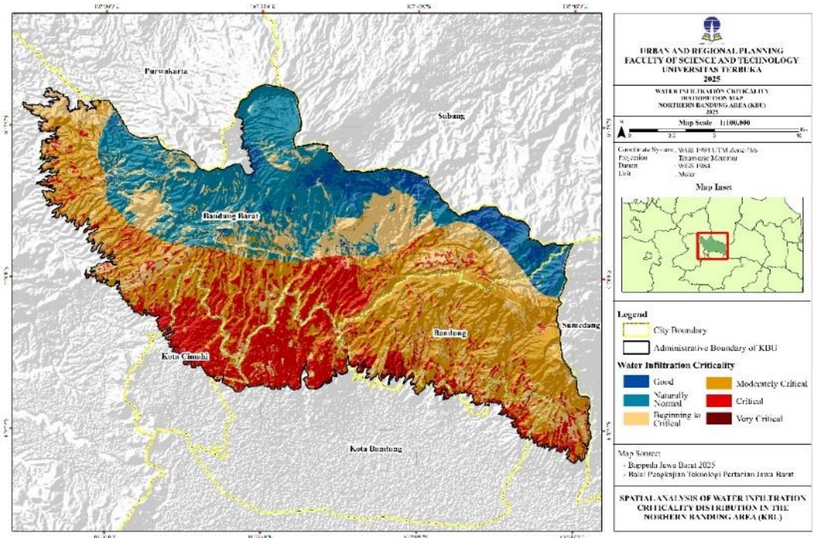

Figure 6. Water infiltration criticality distribution map of the Northern Bandung Area, 2025

Table 10. Water Infiltration Criticality in the Northern Bandung Area (2025)

Total Score	Criticality	Area (km²)	Percentage (%)
> 60	Good	19.08	4.95
54 – 60	Naturally Normal	79.57	20.66
47 – 53	Beginning to Critical	82.48	21.41
40 – 46	Moderately Critical	125.43	32.57
33 – 39	Critical	75.8	19.68
26 – 32	Very Critical	2.87	0.74
	Total	385.23	100

Source: Author's analysis, 2025

The spatial analysis indicates that the North Bandung Area exhibits varying levels of water infiltration criticality influenced by a combination of biophysical factors, including soil type, rainfall, land use, and slope gradient. Based on the overlay and scoring of these four parameters, the study area can be classified into six infiltration categories: good, natural-normal, beginning to critical, moderately critical, critical, and very critical.

From the table, it is evident that the "moderately critical" category is the dominant condition, covering 125.43 km² or 32.57% of the total area. This condition reflects that most parts of the North Bandung Area have begun to experience a decline in infiltration function due to land-cover changes, particularly in rapidly developing urban areas. These findings are consistent with Khasanah et al. (2022), who reported that land-use conversion in the Cimahi region has caused degradation of recharge areas and disrupted hydrological balance.

The "beginning to critical" category (21.41%) is commonly found in areas of West Bandung Regency such as Lembang, Parongpong, and Cisarua. These areas still contain vegetation, but the relatively steep topography accelerates surface runoff, thereby reducing infiltration. Meanwhile, the "naturally normal" category (20.66%) is typically located in areas dominated by non-residential land uses such as forests and plantations, which still support infiltration functions.

In contrast, areas categorized as "good" infiltration are very limited, accounting for only 4.95% of the region, while areas classified as "critical" and "very critical" collectively reach 20.42%.

This distribution not only illustrates the variation in criticality levels but also indicates that water infiltration conditions are uneven and strongly influenced by the region's biophysical factors, such as soil characteristics and land use patterns within the North Bandung Area.

4. Conclusion

The findings of this study indicate that water infiltration conditions in the Northern Bandung Area (KBU) in 2025 are predominantly classified as moderately critical, covering approximately 32% of the region or 125.43 km². This dominance reflects a substantial level of pressure on the land's capacity to absorb water. In contrast, areas with good and natural-normal infiltration conditions occupy only 19.08 km² and 79.57 km², respectively, highlighting the diminishing extent of zones capable of maintaining optimal hydrological functions.

These results align with the analysis of four key biophysical parameters—soil type, rainfall, land use, and slope gradient. Despite the region's high annual rainfall and the prevalence of gentle slopes that would ordinarily support infiltration, these advantages are considerably constrained by the dominance of fine-textured soils such as Latosols, which limit percolation. Additionally, ongoing land-use conversion, particularly the expansion of built-up areas, has further reduced the availability of vegetated surfaces that facilitate infiltration.

Overall, the study underscores a significant decline in infiltration capacity across the KBU, driven by both natural biophysical limitations and accelerated anthropogenic changes. Consequently, efforts to regulate land-use conversion, protect remaining forested areas, and promote sustainable spatial planning are essential to safeguarding the hydrological sustainability of this critical water catchment area.

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