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GIS-Based Spatial Analysis of Groundwater Infiltration Potential in the Batang Pelangai Watershed

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ABSTRACT

The Batang Pelangai watershed plays an important hydrological role in supporting groundwater recharge and regulating surface runoff in the coastal area of West Sumatra. However, land cover changes, topographic variation, and increasing land-use pressure have reduced the capacity of the watershed to absorb water. This study aimed to assess groundwater infiltration potential using a geographic information system-based weighted overlay approach. Four biophysical parameters–soil type, rainfall, land use, and slope gradient–were integrated through scoring, weighting, reclassification, and spatial overlay analysis. The results show that groundwater infiltration potential in the study area is dominated by the somewhat critical category, covering 27,861.04 ha or 49.53% of the total watershed area. The beginning critical category covers 16,488.41 ha or 29.31%, while the very critical category covers 11,452.27 ha or 20.37%. In contrast, areas classified as good and natural normal conditions are very limited, covering only 116.25 ha or 0.21% and 326.03 ha or 0.58%, respectively. These findings indicate that most of the Batang Pelangai watershed has low groundwater infiltration capacity due to the combined influence of slope, soil characteristics, rainfall distribution, and land-use conditions. The resulting infiltration potential map provides spatial information for prioritizing watershed conservation, land rehabilitation, infiltration enhancement, and sustainable water resource management in coastal watershed areas.

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1. INTRODUCTION

The Batang Pelangai Watershed plays a strategic role in maintaining the hydrological function of coastal areas in the Ranah Pesisir District, Pesisir Selatan Regency, West Sumatra Province. This watershed supports groundwater recharge, regulates surface runoff, and provides ecological functions that are important for sustaining land and water resources in coastal environments. Topographically, this area has various slope gradients with dominant soil types in the form of alluvium and latosol, which relatively support the groundwater absorption process (Wiyanti et al., 2022). However, in recent years, the Batang Pelangai Watershed has experienced environmental pressure due to land cover changes triggered by population growth and the intensification of economic activities, particularly the conversion of forests into agricultural land and settlements (Moeck et al., 2024). This condition causes a reduction in natural vegetation as a water catchment area, thereby reducing absorption capacity and increasing surface runoff, which has the potential to increase vulnerability to flooding (Riaz et al., 2025).

The decline in infiltration capacity is a major hydrological problem in watersheds experiencing land degradation. In coastal watersheds, this problem becomes more complex because changes in land cover, slope characteristics, soil properties, and high rainfall can accelerate runoff generation and reduce groundwater storage. This phenomenon is in line with the characteristics of other coastal watersheds in Pesisir Selatan Regency, which have high vulnerability to flooding due to land cover changes and river sedimentation (Umar & Triyatno, 2024). Previous research in watersheds with similar characteristics has shown that increased surface runoff is closely related to decreased water absorption capacity and land degradation; therefore, integrated watershed management efforts based on water resource conservation are needed (Pontoh & W. Ramadhan, 2022). Findings in the Batang Lumpo River also show that the biophysical characteristics of coastal areas influence the dynamics of surface flow and river capacity, indicating the need for integrated management of water catchment areas to support runoff mitigation and coastal area management (Ridwan & Sarjito, 2024).

Infiltration is a key process in the hydrological cycle because it determines the movement of water from the land surface to the soil system. Water enters the soil through pores and gaps, contributing to groundwater storage and recharging (Guo et al., 2022; Alam et al., 2024). The infiltration capacity is influenced by various factors, such as soil type and texture, initial soil moisture, vegetation cover, topography, rainfall, and land use (Mujiyo et al., 2025). When rainfall exceeds the infiltration capacity of the soil, excess water flows as surface runoff, thereby increasing the possibility of erosion, flooding, and degradation of watershed functions. Therefore, identifying the spatial distribution of groundwater infiltration potential is important for understanding the conditions of water catchment areas and determining conservation priorities.

A geographic information system (GIS) approach provides an effective framework for spatially analyzing groundwater infiltration potential. GIS-based analysis enables the integration of multiple biophysical parameters into a single spatial model, allowing areas with different infiltration capacities to be systematically identified and classified. The weighted overlay method is widely used to integrate parameters such as slope gradient, soil type, rainfall, and land use to generate infiltration potential maps (Asri, 2024). This approach can support spatial planning, conservation zoning, and sustainable water resource management (Douass & Ait Kbir, 2020). However, weighted overlay studies often remain limited to producing general infiltration maps and do not always provide sufficient discussion on how the resulting spatial classes reflect land degradation conditions and management priorities at the watershed scale.

Previous studies have demonstrated the usefulness of GIS-based approaches for mapping groundwater recharge and infiltration potential; however, several limitations remain in their application to coastal watersheds. Many studies emphasize the technical integration of spatial parameters, while the interpretation of infiltration classes in relation to watershed degradation, surface runoff control, and conservation planning is still limited. In addition, the application of national scoring and weighting systems to local watershed conditions requires a clearer explanation because local variations in slope, soil type, rainfall, and land use may influence the final classification. Therefore, further analysis is needed to evaluate groundwater infiltration potential in the Batang Pelangai Watershed by integrating biophysical parameters and linking the results with watershed conservation needs.

Therefore, this study aimed to map and analyze groundwater infiltration potential in the Batang Pelangai watershed using a geographic information system approach through a weighted overlay method by integrating rainfall, slope gradient, soil type, and land use parameters. The novelty of this study lies in its spatial evaluation of groundwater infiltration potential in a coastal watershed setting and its use of infiltration condition classes as a basis for identifying conservation and watershed management priorities. The research results are expected to provide spatial information to support land conservation, water resource management, and sustainable surface runoff control in the Batang Pelangai watershed.

2. METHOD

2.1. Time and Location of Research

This research was conducted in May 2025 in the Ranah Pesisir District, Pesisir Selatan Regency, West Sumatra Province. Geographically, Pesisir Selatan Regency is located at coordinates 00°59'–02°28'6" South Latitude and 100°19'–101°18' East Longitude, with a land area of approximately 5,749.89 km² and a coastline of approximately 234 km (Bappeda Litbang Pesisir Selatan Regency, 2018).

The research location was selected because the Batang Pelangai Watershed is part of a coastal watershed system that has experienced land-use pressure and requires spatial information related to groundwater infiltration potential. This area has varied topography, with elevations ranging from 0–500 meters above sea level and an average annual rainfall of 3,000–4,000 mm. Land cover in this area consists of protected forests, agricultural land, plantations, settlements, and shrubland. According to BPS data, the Ranah Pesisir District has a population of approximately ±28,000 people. Administratively, Pesisir Selatan Regency is bordered by Padang City to the north, Muko-Muko Regency, Bengkulu Province to the south, the Indian Ocean to the west, and Solok Regency, South Solok Regency, Kerinci Regency, and Sungai Penuh City to the east (Bappeda Litbang Pesisir Selatan Regency, 2018).

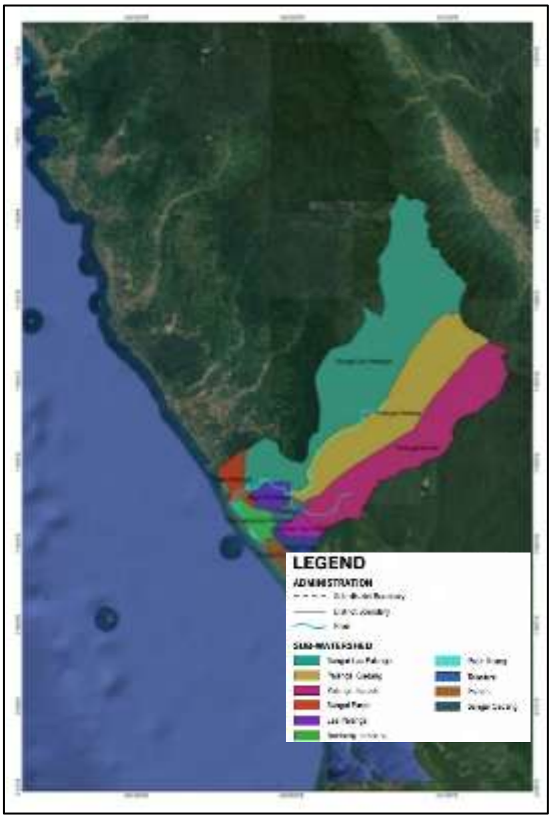

Figure 1. Map of the research location

2.2. Tools and Materials

The tools and materials used in this study are presented in Table 1. The materials consisted of spatial and non-spatial data used to analyze the physical parameters that influence groundwater infiltration potential, including satellite imagery, digital elevation model (DEM), soil type map, rainfall data, slope map, and land use map. The tools used in this study included GIS software for spatial processing and Microsoft Office software for tabulation and data preparation.

Satellite imagery was used for land cover analysis, while the DEM data were used to derive slope and elevation information. Soil type data were used to identify soil characteristics related to infiltration capacity, and rainfall data were used to represent water input in the study area. All spatial data were processed in a GIS environment to ensure that each parameter could be integrated through reclassification, scoring, weighting, and overlay analysis.

Table 1. Research Tools and Materials

No.	Tools/Materials	Data source	Function
1	Satellite Imagery	Landsat 8	Land cover analysis
2	DEM Map	Ina-Geoportal	Slope and elevation analysis
3	Soil Type Map	Geospatial Information Agency	Identify soil types
4	Rainfall Map	Meteorology, Climatology, and Geophysics Agency	Analysis of potential rainfall
5	Slope Map	DEM	Analyzing land slope
6	Land Use Map	Geospatial Information Agency	Identifying land cover.
7	GIS Software	ArcGIS/QGIS	Spatial data processing and analysis
8	Microsoft Office Software	Microsoft Word/ Microsoft Excel;	Used to enter data

2.3. Types of Research

This study used a descriptive quantitative survey method by applying a geographic information system-based spatial analysis approach. The analysis was conducted using a weighted overlay technique, which involves assessment and weighting to evaluate groundwater infiltration potential. The descriptive quantitative method was used to describe the physical conditions of the area systematically, accurately, and objectively based on parameters that influence infiltration capacity (Assayakurrohim et al., 2023).

The data used included land cover, soil type, slope gradient, and rainfall obtained from various primary and secondary sources. All spatial data were standardized using the Universal Transverse Mercator projection system, WGS 1984 Zone 47S. Before overlay analysis, all spatial layers were checked for coordinate system consistency, clipped according to the Batang Pelangai watershed boundary, and adjusted to the same spatial extent to avoid mismatch between layers during analysis. The data were then processed through scoring and weighting, followed by an overlay intersect method to identify overlapping areas among the parameters.

The analysis phase began with data collection and preprocessing, including geometric correction, coordinate system standardization, and preparation of thematic layers. Next, each parameter was reclassified into several classes based on its influence on the groundwater infiltration. Each class was assigned a specific score, with higher values indicating better infiltration capacities.

After the reclassification process, each parameter was weighted based on its importance to the infiltration process. The weighted overlay process was performed by multiplying each parameter score by its weight and then summing the results to produce a final value for groundwater infiltration potential. Mathematically, this analysis can be formulated as

$$\text{Infiltration Potential} = (w_1 \times x_1) + (w_2 \times x_2) + (w_3 \times x_3) + (w_4 \times x_4) \tag{1}$$

where w is the parameter weight, and x is the reclassification score.

The overlay process produced a zoning map of groundwater infiltration potential in five categories: good, natural normal, beginning critical, somewhat critical, and very critical conditions. These categories were aligned with those in the Results and Discussion sections to avoid differences between the method and interpretation. Validation involved comparing the spatial model with field observations and secondary hydrological information, focusing on land cover, slope, soil characteristics, shallow groundwater, and hydrological indications at selected locations.

2.4. Data Collection, Processing, and Analysis Methods

The study used primary and secondary data sources. Primary data were obtained through field surveys and shallow well observations at 30 locations in villages across Ranah Pesisir District. Sampling points were selected purposively based on land use, slope gradient, and soil type to represent potential infiltration classes. Field validation examined land cover, soil permeability, groundwater depth, slope, and hydrological evidence. Direct ground checks ensured that the spatial analysis matched actual conditions. Survey data supported the interpretation of environmental conditions and verified the groundwater infiltration potential modeling results.

Secondary data used in this study included topographic maps, soil type maps, land cover data, DEM, and rainfall data obtained from relevant agencies and official data sources, such as the Geospatial Information Agency, the Meteorology, Climatology, and Geophysics Agency, and other government agencies. Rainfall data were obtained for the 2015–2025 period from five observation stations in and around the Batang Pelangai watershed. The point rainfall data were interpolated using the inverse distance weighting method to produce a spatial rainfall distribution layer.

The study employed weighted overlay, involving reclassification, scoring, and parameter weighting, to map groundwater infiltration zones. Parameters followed Regulation of the Minister of Forestry of the Republic of Indonesia No. 32/Menhut-II/2009: soil type, rainfall, land use, and slope (Minister of Forestry Regulation No. 32/Menhut-II/2009, 2015). Initial processing standardized projections, clipped data to the Batang Pelangai Watershed boundary, interpolated rainfall, and reclassified parameters by infiltration capacity. Subsequently, data were evaluated for impacts on groundwater infiltration. Each parameter was weighted by significance and combined through overlay intersection to generate a groundwater infiltration potential index.

Table 2. Water Absorption Area Parameter Values

Parameter	Weight
Soil Type	5
Rainfall	4
Land Use	3
Slope	2

The weighting scheme used in this study refers to Regulation of the Minister of Forestry of the Republic of Indonesia No. 32 of 2009 because the guideline was formulated based on scientific considerations and has been widely used in evaluating watershed conditions in Indonesia. The parameters used, such as slope gradient, soil type, rainfall, and land use, are the main factors that directly influence infiltration and runoff processes, making them relevant for application to the Batang Pelangai watershed.

However, applying these regulatory weights to the local watershed scale has limitations because the biophysical characteristics of each region can vary significantly. Therefore, the analysis results of this study are sensitive to the weighting scheme used. Changes in the weighting values could potentially affect the final classification of water catchment potential. Therefore, the use of this scheme is considered a representative initial approach; however, further testing through sensitivity analysis or field-based calibration is required to improve the accuracy and suitability of the results for the local context.

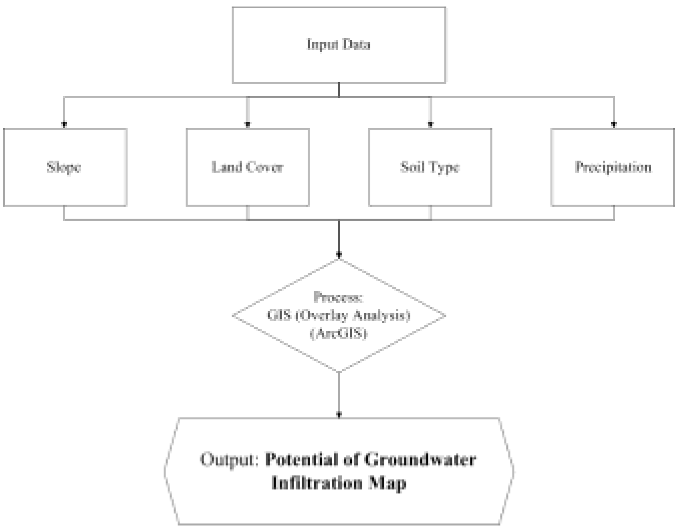

Figure 2. Research Flowchart

3. RESULTS AND DISCUSSION

3.1. Spatial Parameters Determining Water Infiltration Potential

Slope is a physical factor that controls the movement of water on the land surface and into the soil. Areas with gentle slopes generally provide greater opportunity for rainwater to infiltrate because surface flow moves more slowly, whereas steeper slopes tend to accelerate runoff and reduce the time available for infiltration. The smaller the slope, the better the infiltration capacity of the area, whereas steeper slopes tend to have lower infiltration potential (Qur'ani et al., 2022).

Based on the slope map, the study area was classified into five slope classes with different scores and weights. The 0–8% slope class was assigned the highest score because flat to gentle areas have better opportunities for water to infiltrate, whereas the >40% slope class was assigned the lowest score because steep slopes increase surface runoff. A slope of 0–8% has very high infiltration with the highest score of 5, while a slope of >40% has low infiltration with the lowest score of 1, all using a weight of 2.

The results show that gentler slopes have greater infiltration capacity, whereas steeper slopes have lower infiltration because rainwater flows quickly as surface runoff rather than into the soil. This indicates that slope gradient controls variation in groundwater infiltration potential in the Batang Pelangai watershed. The prevalence of moderate to steep slopes in parts of the area indicates limited infiltration potential and runoff during rainfall.

Table 3. Score Results and Slope Weights in Ranah Pesisir District

Slope Gradient (Slope)%	Infiltration	Score	Weight
0-8%	Big	5	2
8-15%	Large enough	4	2
15-25%	Currently	3	2
25-40%	A bit small	2	2
>40%	Small	1	2

Soil type is a main parameter in determining water catchment areas. Different soils have different infiltration capacities controlled by texture, structure, porosity, and permeability. Coarse-grained or sandy soils have higher infiltration rates than fine-textured soils, clay and silt, due to pore size differences. Higher permeability accelerates drainage and infiltration (Kholis & Rendra, 2022).

The soil types in this study were classified based on their infiltration capacity using the National Soil Classification System. Regosol had the highest infiltration capacity with a score of 5, followed by alluvial and andosol with a score of 4, latosol with a score of 3, lithosol with a score of 2, and grumosol with the lowest infiltration capacity with a score of 1. This classification reflects the differences in soil texture and permeability that influence the ability of the soil to transmit water into the subsurface layer.

Soil classification was adjusted to the national system for consistency. All soil types were assigned the same weight (5) for analysis of groundwater infiltration potential. Soil had the highest weight, indicating it was key in water absorption conditions; thus, its effect must be interpreted with land use, rainfall, and slope gradient.

Table 4. Score Results and Weighting of Soil Type Parameters in Ranah Pesisir Regency

Soil Type	Infiltration	Score	Weight	Total
Regosol	Big	5	5	25
Alluvial and Andosol	Large enough	4	5	20
Latosol	Currently	3	5	15
Lithosol	A bit small	2	5	10
Grumosol	Small	1	5	5

Rainfall influences the hydrological response of watersheds. In this study, it was not treated as a determinant of infiltration capacity, but as an indicator of surface water availability that may infiltrate soil or become runoff depending on slope, soil type, and land use. High rainfall intensity increases potential infiltration, but effectiveness depends on regional physical characteristics.

If the soil infiltration capacity is exceeded, excess water becomes surface runoff and may contribute to flood potential. Therefore, the rainfall parameter in this analysis represents the spatial distribution of water input that interacts with other biophysical parameters to determine groundwater infiltration potential.

Rainfall in the study area was classified into five categories. The spatial distribution of rainfall shows that water input varies across the Batang Pelangai Watershed, which influences the amount of water available for infiltration and runoff generation in the watershed. The northern region, such as Nagari Sungai Liku Pelangai, has relatively low rainfall of 2,500–3,500 mm/year, with a score of 2. The central region, such as Pelangai Gadang, has moderate rainfall of 3,500–4,500 mm/year with a score of 3, whereas the southern to southwestern regions, such as Pelangai Kaciak and Sungai Tunu Utara, show very high rainfall of >5,000 mm/year with a score of 5.

In general, the study area is characterized by high rainfall, particularly in the southwestern region. High rainfall may increase the opportunity for groundwater recharge in areas with good soil permeability, gentle slopes, and vegetated land. However, in areas with steep slopes, low-permeability soils, and intensive land use, high rainfall is more likely to increase the surface runoff. Therefore, rainfall must be interpreted as an interacting factor, rather than a standalone indicator of infiltration capacity.

Table 5. Score Results and Weighting of Rainfall Parameters in Ranah Pesisir Regency

Rainfall (mm/year)	Infiltration	Score	Weight	Total
>5,000	Big	5	4	20
4,500-5,000	Large enough	4	4	16
3,500-4,500	Currently	3	4	12
2,500-3,500	A bit small	2	4	8
<2,500	Small	1	4	4

Land use is an important parameter in determining the condition of water catchment areas. Vegetated land, such as forests and plantation areas, generally supports infiltration through canopy interception, root systems, and better soil structure, whereas settlements and intensively used agricultural land tend to reduce infiltration capacity. Land use that experiences significant changes will affect the quality and extent of water catchment areas in a region (Lucyana & Azwar, 2022).

The land use map shows various land use types in the study area that affect water absorption capacity. Forests have the highest capacity because vegetation improves soil structure, protects the surface from rainfall impact, and supports root channels that enhance infiltration. Forests score 5 with weight 3, followed by plantations (4) and shrubs (3). Fields and dry fields score 2, while settlements and rice fields have the lowest capacity, scoring 1.

Land use variation in the area reflects human activities and natural conditions. Settlements and agricultural land can reduce groundwater absorption when replacing forests and shrubs. This conversion weakens watershed function by reducing infiltration and increasing runoff, making land use important for identifying areas requiring conservation, rehabilitation, and infiltration enhancement.

Table 6. Land Use Assessment

Land Use	Infiltration	Score	Weight	Total
Forest	Big	5	3	15
Plantation	Large enough	4	3	12
Bush	Currently	3	3	9
Fields, Dry Fields	A bit small	2	3	6
Settlements, Rice Fields	Small	1	3	3

Figure 2 shows the spatial distribution of four parameters determining groundwater infiltration potential in the Batang Pelangai watershed: slope, soil type, rainfall, and land use. Their spatial characteristics influence infiltration. Gentle slopes, permeable soils, high vegetation cover, and suitable rainfall support water absorption, whereas steep slopes, less permeable soils, intensive land use, and runoff potential reduce infiltration. These patterns underpin variation before final weighted overlay classification.

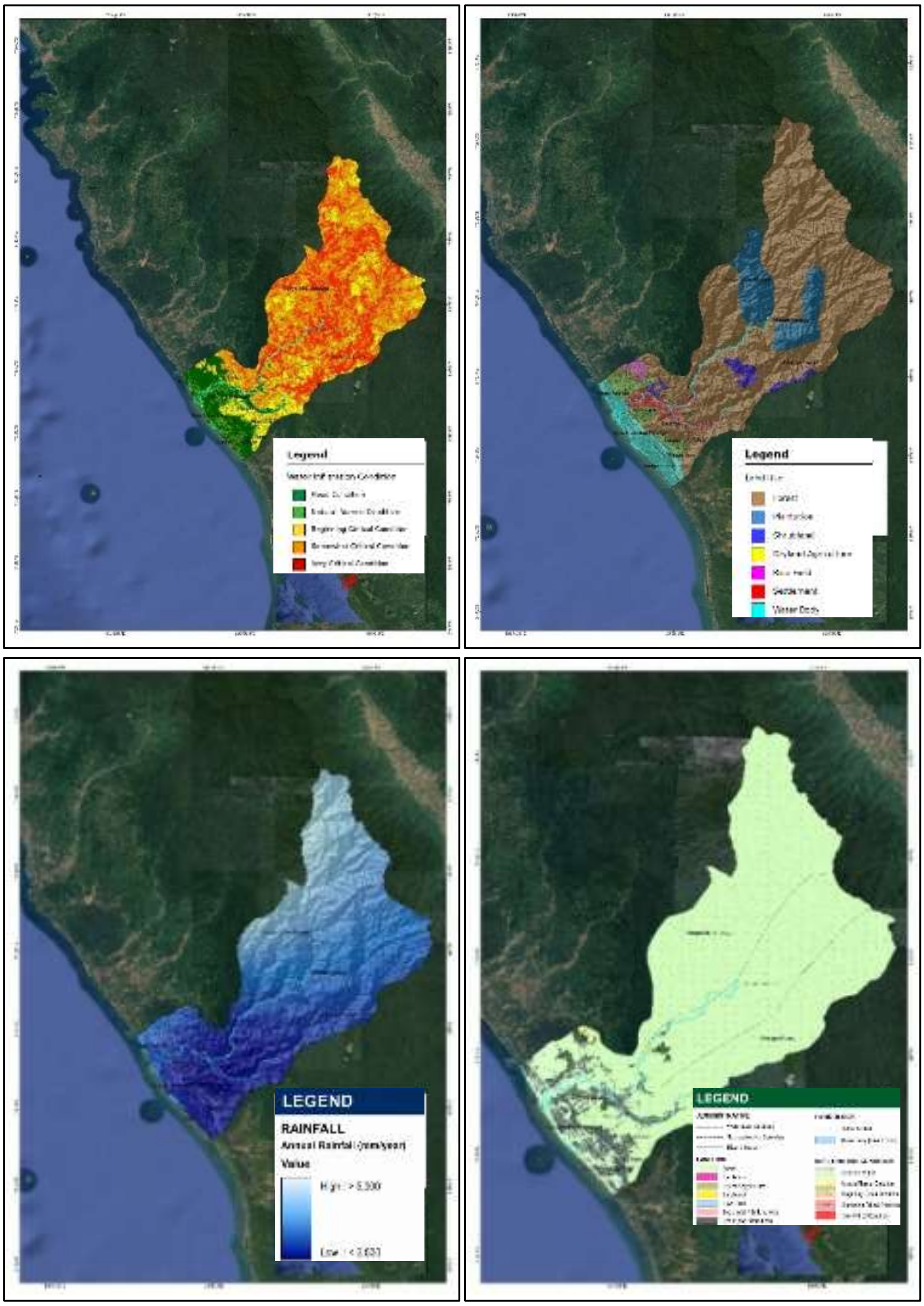

Figure 2. Spatial parameters (from top left to clockwise), a) Slope, b) Soil type, c) Rainfall, and d) Land Use Map

3.2. Water Infiltration Conditions

To assess water catchment conditions, scoring and weighted overlay techniques were applied to regional physical parameters. The analysis combined soil type, rainfall, land use, and slope gradient to classify groundwater infiltration potential spatially within the Batang Pelangai watershed. Using overlay methods, maps of these factors were examined to generate water catchment area maps (Pratama et al., 2024). The resulting index values were categorized into five groups: good, natural normal, beginning critical, somewhat critical, and very critical conditions. These classifications depict the distribution of groundwater infiltration potential throughout the Batang Pelangai watershed.

Table 7. Water Absorption Area Condition Criteria

Total Score	Criteria
>48	Good Condition
44-47	Natural Normal Conditions
40-43	Conditions Begin to Become Critical
37-39	His condition is quite critical
<37	Very Critical Condition

Weighted overlay analysis identified five water infiltration classes in the Batang Pelangai watershed. The Ranah Pesisir district comprised five classes. The good class covers only 116.25 ha (0.21 %), and the natural normal class 326.03 ha (0.58 %), indicating limited areas with high water absorption capacity.

Table 8. Assessment and Value of Criteria for Water Absorption Area Conditions in Coastal Area Districts

Water Infiltration Classification	Ranah Pesisir District Water Catchment Area (Ha)	Percentage (%)
Good Condition	116.25	0.21%
Natural Normal Conditions	326.03	0.58%
Conditions Begin to Become Critical	16,488.41	29.31%
His condition is quite critical	27,861.04	49.53%
Very Critical Condition	11,452.27	20.37%
Total	56,243.99	100%

The area is dominated by the somewhat critical category, covering 27,861.04 ha (49.53%), followed by the beginning critical category with 16,488.41 ha (29.31%) and the very critical category with 11,452.27 ha (20.37%). Natural normal and good conditions occupy only 0.58% and 0.21%, indicating low infiltration in the Batang Pelangai Watershed and need for conservation.

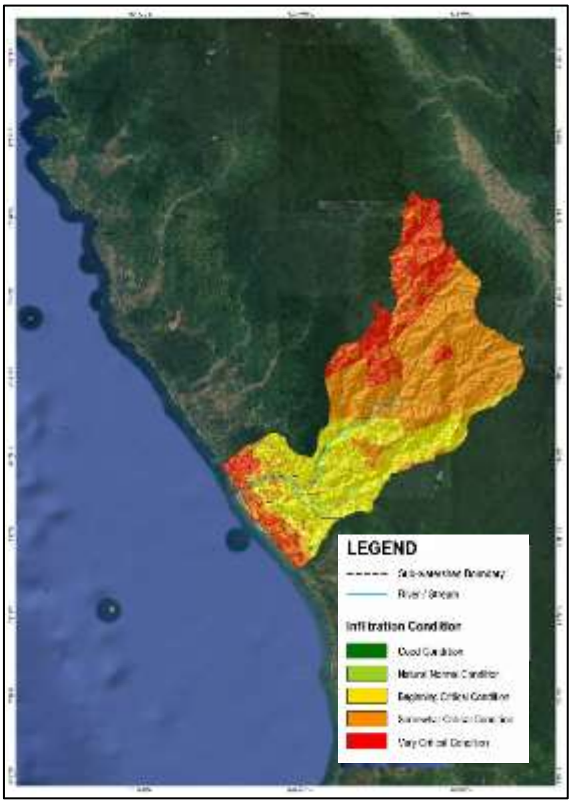

Figure 3. Water Absorption Map

In contrast, the natural normal and good condition categories were only found in limited areas, covering 0.58% and 0.21%, respectively. These areas generally represent locations where biophysical conditions still support infiltration, particularly where the slope is relatively gentle, vegetation cover is better maintained, and soil conditions are more favorable. These results indicate that the areas with optimal infiltration capacity in the Batang Pelangai watershed are limited.

The dominance of the somewhat critical and very critical categories has important hydrological implications. Areas with reduced infiltration potential may contribute to higher surface runoff, lower groundwater recharge, and increased vulnerability to hydrological hazards during high-rainfall periods. However, the resulting map should be interpreted as an infiltration potential map rather than a direct flood hazard map. Flood risk assessment requires additional hydrological validation, including runoff data, inundation history, river discharge, and observed flood events. Therefore, the results of this study provide an initial spatial basis for identifying water catchment conditions and prioritizing conservation efforts.

Compared with previous studies, the results support the view that watershed infiltration capacity is strongly influenced by land use, soil type, slope, and rainfall. Studies on groundwater infiltration and recharge mapping have shown that GIS-based spatial analysis is useful for identifying priority zones for water resource management (Mohan et al., 2018; Wiyanti et al., 2022; Kholis & Rendra, 2022). The advantage of the present study is that the infiltration classification is directly linked to watershed management needs in a coastal watershed context, particularly for identifying areas that require rehabilitation, runoff control, and infiltration improvement. Nevertheless, the use of regulatory weights has limitations because local watershed characteristics may vary; therefore, future analysis should include field-based calibration and sensitivity testing.

3.3. Watershed Management Recommendations

Water catchment management should be based on the spatial classification results obtained from overlay analysis. Because approximately 69.90% of the study area falls into the somewhat critical and very critical categories, conservation planning should prioritize areas where low infiltration potential is associated with steep slopes, non-vegetated land use, and soil types with limited permeability. Based on the analysis map, priority management zones are concentrated in areas with moderate to steep slopes, built-up or non-vegetative land use, and soils with low infiltration capacity.

In the beginning critical zone, which is generally associated with plantation and field areas on slopes of 15–25%, management should focus on improving soil quality and maintaining productive vegetation. Recommended actions include adding organic matter, applying soil conservation practices, maintaining vegetation cover, and reducing land management practices that accelerate runoff. In the somewhat critical zone, which is commonly associated with slopes of 25–40%, settlements, and rice fields, mechanical conservation techniques, such as terracing and runoff control channels, are recommended. These interventions are needed to slow surface flow, increase water retention time, and improve the opportunity for infiltration.

The critical zone requires intensive intervention because it represents areas with the lowest infiltration potential. In areas with slopes greater than 40%, dense settlements, dry fields, lithosol, or grumosol soils, conservation should prioritize infiltration wells, biopores, vegetative terracing, ground cover plants, and permanent reforestation. These measures are important for reducing surface runoff and restoring the hydrological function of degraded catchment areas.

Spatially, this recommendation is aimed at mapping units or priority zones that can be further integrated into sub-watershed planning or local administrative areas (Harris 2015). For practical implementation, the priority zones shown in the water absorption map should be linked with village or nagari administrative boundaries so that conservation programs can be directed toward specific management units. This approach will make the results more useful for local planning, watershed rehabilitation, and sustainable water resource management in the region.

Table 13. Management Recommendations Based on Water Infiltration Conditions in the Batang Pelangai Watershed

Water Infiltration Condition	Priority Management Direction	Recommended Management
Good Condition	Protection	Maintain existing vegetation cover and avoid land conversion in areas with high infiltration capacity.
Natural Normal Condition	Preventive conservation	Preserve vegetation cover, maintain soil structure, and apply light conservation practices to prevent degradation.
Beginning Critical Condition	Soil and vegetation improvement	Improve soil quality through organic matter addition, vegetation management, and simple soil conservation practices.
Somewhat Critical Condition	Land rehabilitation	Apply terracing, infiltration channels, runoff control, and vegetation reinforcement to improve water absorption.
Very Critical Condition	Intensive conservation	Prioritize reforestation, infiltration wells, biopores, ground cover plants, and strict land-use control.

4. CONCLUSIONS

This study demonstrates that the Batang Pelangai watershed is dominated by areas with reduced potential for groundwater infiltration. Weighted overlay analysis indicates that the somewhat critical condition is the dominant class, covering 27,861.04 ha or 49.53% of the study area, followed by the beginning critical condition with 16,488.41 ha or 29.31% and the very critical condition with 11,452.27 ha or 20.37%. In contrast, areas classified as good and natural normal conditions are very limited, covering only 116.25 ha or 0.21% and 326.03 ha or 0.58%, respectively. These findings indicate that slope gradient, soil type, rainfall, and land use collectively influence the low groundwater infiltration potential in most parts of the watershed. The resulting spatial information can support conservation planning by prioritizing somewhat critical and very critical zones for land rehabilitation, runoff control, infiltration wells, biopores, and vegetation restoration. However, this study is limited by the use of available spatial data and regulatory weighting; therefore, future research should include direct infiltration measurements, groundwater level observations, and sensitivity analysis to improve model accuracy and local applicability.

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