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Original Article

Mapping of Groundwater Potential Zones Using the Analytic Hierarchy Process(AHP) and Geographic Information System (GIS) Approach in Batang District,Jeneponto Regency, Indonesia

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ABSTRACT
This study is a quantitative descriptive study with a spatial approach that aims to map groundwater potential zones in Batang District, Jeneponto Regency, using the Analytic Hierarchy Process (AHP) and Geographic Information System (GIS) methods. The parameters used in this study include rainfall, soil type, slope, geology, drainage density, land cover, and straightness density. The weight of each parameter was determined using the AHP method, then weighted overlay was performed to produce a map of groundwater potential zones. The results of the study show that the Batang District is divided into three categories of groundwater potential zones, namely low category with an area of 455 hectares (13.53%), medium category with an area of 2,226 hectares (66.07%), and high category with an area of 687 hectares (20.40%). Validation of nine observation points showed that the ROC Curve statistical analysis produced an Area Under Curve (AUC) value of 0.92, indicating that the AHP model has excellent classification capabilities.

KEYWORDS
Ground Water, Potential Zones, Analytic Hierarchy Process, Geographic Information System

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INTRODUCTION

Hydrology comes from the Greek word "hydrologia," which means "the science of water." Hydrology is a branch of geography that studies the movement, distribution, and quality of water throughout the earth, including the hydrological cycle and water resources (Efendi, 2021). Water is a natural resource that plays an important role in the survival of all living things, including humans (Samekto & Winata, 2016). Groundwater is water that moves in the soil, found in the spaces between soil particles, forming streams in rock fractures (Sosrodarsono, 1999; Jabbari et al., 2018). Groundwater is the largest freshwater reserve that supports domestic, agricultural, and industrial water supplies (Mukherjee et al., 2024).

According to Biswas and Tortajada (2024), groundwater providing approximately 42% of global irrigation water, 36% of drinking water, and 24% of industrial water. Data from United Nations Water (2022) also shows that more than 2 billion people globally depend heavily on groundwater as their only source of drinking water. Groundwater is divided into two types, namely shallow groundwater and deep groundwater. Shallow groundwater experiences significant fluctuations due to seasonal changes, while deep groundwater is almost unaffected by the seasons. Both the quantity and quality of groundwater tend to be stable (Baharudin et al., 2023).

The availability of clean water is becoming increasingly crucial, in line with the United Nations Sustainable Development Goals (SDGs) number six, which emphasizes the importance of ensuring access to and management of clean water and sustainable sanitation. However, the availability of groundwater as the main source for basic human needs is declining. This decline is not proportional to the increase in groundwater consumption due to urbanization, population growth, and increased human activity (Nugroho et al., 2022). Population growth and unplanned development have caused serious pressure on groundwater availability, which is increasingly threatened by overexploitation and contamination (Husna et al., 2023).

Groundwater potential zones refer to the determination of an area based on the possibility of groundwater sources. Various techniques can be applied to provide information about groundwater potential, either through direct or indirect methods (Agarwal & Garg, 2016; Putra, 2018). In studies to determine groundwater potential zones, many factors (e.g., lithology, soil texture, land use, drainage density, straight line density, geomorphology, slope, topographic wetness index, soil

depth, rainfall, distance to rivers, groundwater table depth, and digital elevation models) related to groundwater storage based on geological, hydrological, hydrogeological, meteorological, and terrain features are used as decision criteria for AHP multi-criteria decision analysis (Raju et al., 2019; Yildirim, 2021).

Indonesia has abundant natural resources in various regions, but in terms of resource utilization, it is still lacking. According to Samekto & Winata (2016), Indonesia is among the ten countries with abundant water resources, but there are fundamental problems in its utilization. First, seasonal variations and the imbalance in water distribution pose challenges. During the rainy season, several regions in Indonesia experience significant excess water, which can cause flooding and other damage. Conversely, during the dry season, several regions experience water shortages and drought.

Jeneponto Regency is one of the regencies in South Sulawesi Province that faces drought and clean water crises. Currently, 8 of the 11 subdistricts in Bumi Turatea are experiencing the effects of drought (A.P Pratama, 2023). Most areas in Jeneponto Regency experience drought, especially during the dry season. There are 113 villages and subdistricts spread across 11 subdistricts in Jeneponto Regency that experience clean water shortages (Wakhyono, 2018; Agussalim & Rizal, 2021).

According to the Indonesia Urban Water, Sanitation, and Hygiene report (2017), most of the population in Jeneponto Regency still depends on shallow groundwater (dug wells), water from the PDAM piping system, springs, and groundwater from deep wells to meet their household clean water needs. The challenges in providing clean water in Jeneponto Regency are the coverage of PDAM services, which only reaches 10.7%, and low production capacity.

Batang Subdistrict is one of the subdistricts in Jeneponto Regency that has problems with drought and clean water crisis. According to A.P Pratama (2024), Batang Subdistrict is a subdistrict whose area is affected by drought and clean water crisis. Batang Subdistrict had a population of 19,494 in 2017, which increased to 21,958 in 2023 (Jeneponto Regency Central Statistics Agency, 2024). This shows that the demand for clean water has increased significantly in line with population growth (Mardika et al., 2024).

This situation emphasizes the need for more specific local studies to support effective water resource management. For example, previous research has been conducted to map groundwater potential zones using Geographic Information Systems (GIS) and the Analytical Hierarchy Process (AHP) approach. Research by Purwanto et al. (2023) entitled "Identification of Groundwater Potential Zones Using Remote Sensing and is a drought-prone area but has not received much attention in systematic groundwater potential studies. The novelty of this study lies in the application of the AHP–GIS method with seven main parameters tailored to GIS Technique: A Case Study of the Ketungau Basin in Sintang, West Kalimantan". This study used parameters such as drainage density, slope, straightness density, lithology, soil type, and land use/land cover. The classification of groundwater potential in this study consisted of five potential classes. A similar study was conducted by Yildirim (2022) in Turkey, which used ten parameters, including slope, drainage density, straightness density, rainfall, soil type, and land use/land cover, to obtain five potential classes. These findings show that the integration of GIS with the AHP method can provide an overview of groundwater zoning in various regions with different characteristics.

Although the AHP–GIS approach has been widely used in groundwater potential mapping research, most studies still focus on the district or provincial scale with a wide coverage area, thus providing less detail at the subdistrict or local level. This study aims to fill this gap by examining Batang Subdistrict, Jeneponto District, which is a drought-prone area but has not received much attention in systematic groundwater potential studies. The novelty of this study lies in the application of the AHP–GIS method with seven main parameters tailored to regional conditions and supplemented by field validation, so that the results not only provide a more specific representation of groundwater potential at the subdistrict

scale but also increase the accuracy of the research results. Therefore, this study aims to answer the following three questions: first, what are the results of the groundwater potential parameters in Batang Subdistrict; second, how is the groundwater potential zone classification map generated; and third, what are the results of the validation of the groundwater potential.

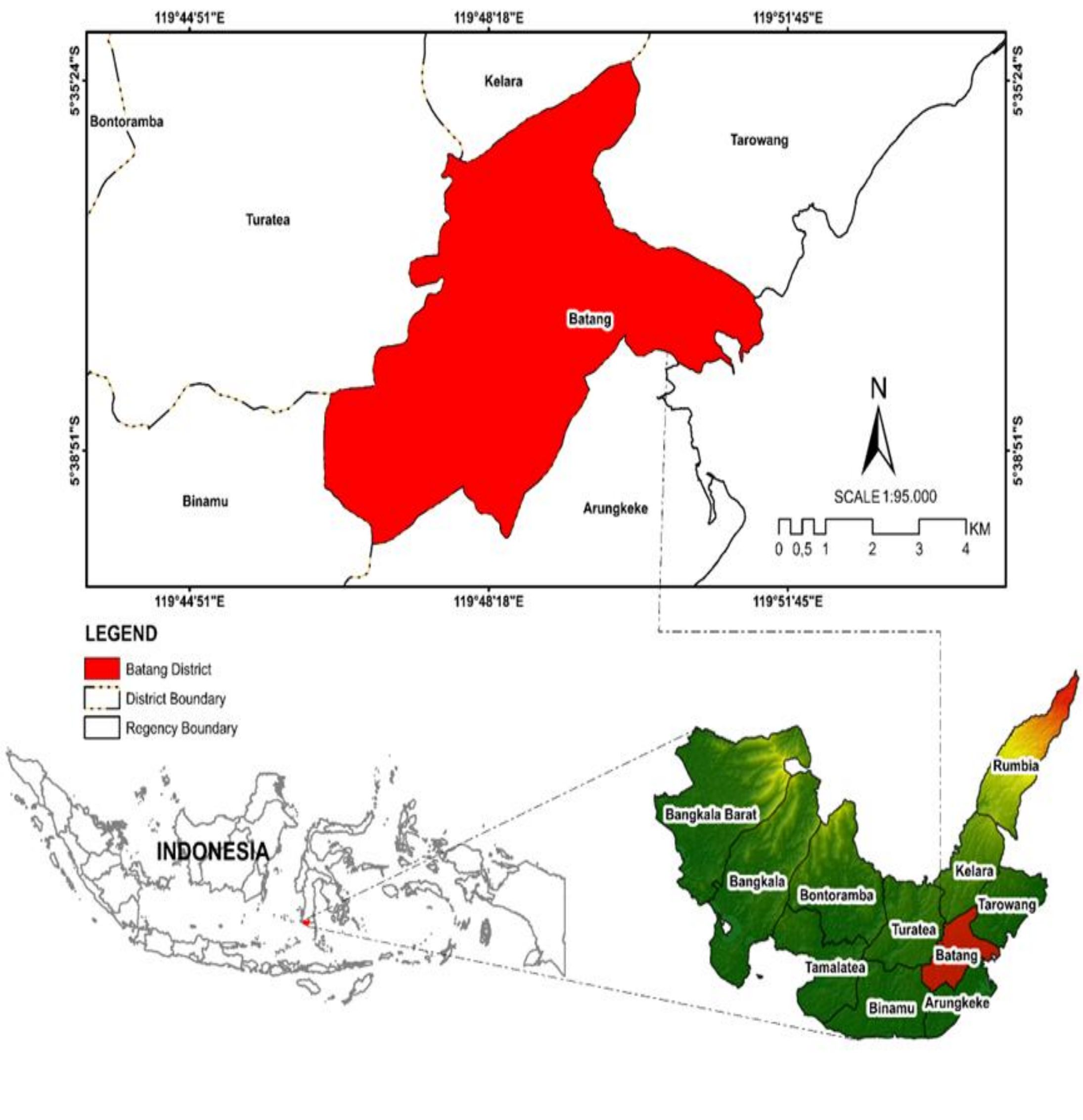

Figure 1. Research Location Map

METHOD

Research Location

The study area is located in Batang Sub-district, Jeneponto Regency, which is one of 11 sub-districts in Jeneponto Regency. It is bordered by Kelara Sub-district to the north, Tarowang Sub-district to the east, Binamu Sub-district to the west, and Arungkeke Sub-district to the south. Batang Sub-district consists of 4 villages and 2 urban wards, covering a total area of 33.04 km^2 (Statistics Indonesia of Jeneponto Regency, 2024). Batang Sub-district was selected as the research location because it is a drought-prone area with a clean water crisis, making the mapping of groundwater potential essential in supporting the community's water needs. Furthermore, studies related to groundwater potential in Batang Sub-district remain limited to date, so this research is expected to provide information and contribute to water resource management.

Research Approach

The approach used in this study is a spatial approach, emphasizing the analysis of spatial existence as a unified system that accommodates various human activities, particularly in understanding geospheric phenomena related to groundwater potential (Yunus, 2008; Sulpiana & Nurhalim, 2023). According to Rahman (2024), GIS-based spatial mapping is an effective approach for understanding the relationships among environmental factors. This study involves spatial data processing and parameter weight analysis using the Analytic Hierarchy Process (AHP) and Geographic Information Systems (GIS). The AHP and GIS approaches were used because they have been proven effective in identifying groundwater potential zones with a high degree of accuracy (Naeem et al., 2024).

Research Procedure

1. **Preparation Stage**

This initial stage requires planning to determine the research objectives, hypotheses, and methods to be used. This stage also encompasses data collection and the review of literature related to groundwater potential, in order to understand the background, objectives, and theoretical framework of the intended research, as well as the procurement of necessary equipment and materials.

Data Collection Stage

Three types of data were used for map production: vector data consisting of geological data and soil type data; raster data consisting of slope, lineament density, drainage density, and rainfall data; and secondary data containing groundwater depth data for Batang Sub-district, Jeneponto Regency.

Table 1. Data and Data Sources

No.	Parameter	Data	Year	Source
1	Slope	DEM SRTM 10M	2025	https://browser.dataspace.copernicus.eu/
2	Drainage Density	DEM SRTM 10M	2025	https://browser.dataspace.copernicus.eu/
3	Lineament Density	DEM SRTM 10M	2025	https://browser.dataspace.copernicus.eu/
4	Land Cover	Sentinel-2	2024	https://livingatlas.arcgis.com/landcoverexplorer
5	Geology	Shapefile	–	Department of Energy and Mineral Resources of South Sulawesi Province
6	Soil Type	Shapefile	2007	Food and Agriculture Organization (FAO)
7	Rainfall	Rainfall Data	2024	Statistics Indonesia (BPS)
8	Groundwater Depth (Secondary Data)			

Source: Author's Compilation (2025)

Map Production Stage

Map production was carried out using ArcGIS and PCI Geomatica. The slope map was derived from the DEM using the slope tool, reclassified into five classes, clipped to the study area boundary, and converted to polygon format. The river network was extracted from the DEM to produce a drainage density map. The lineament density map was created by extracting geological structures (faults and folds) using PCI Geomatica, then analyzed using line density in ArcGIS. The land cover map was obtained from the Esri Land Cover Explorer, while the geology and soil type maps were clipped to the study area. The rainfall map was produced through IDW interpolation, reclassified, clipped, and converted to polygon format.

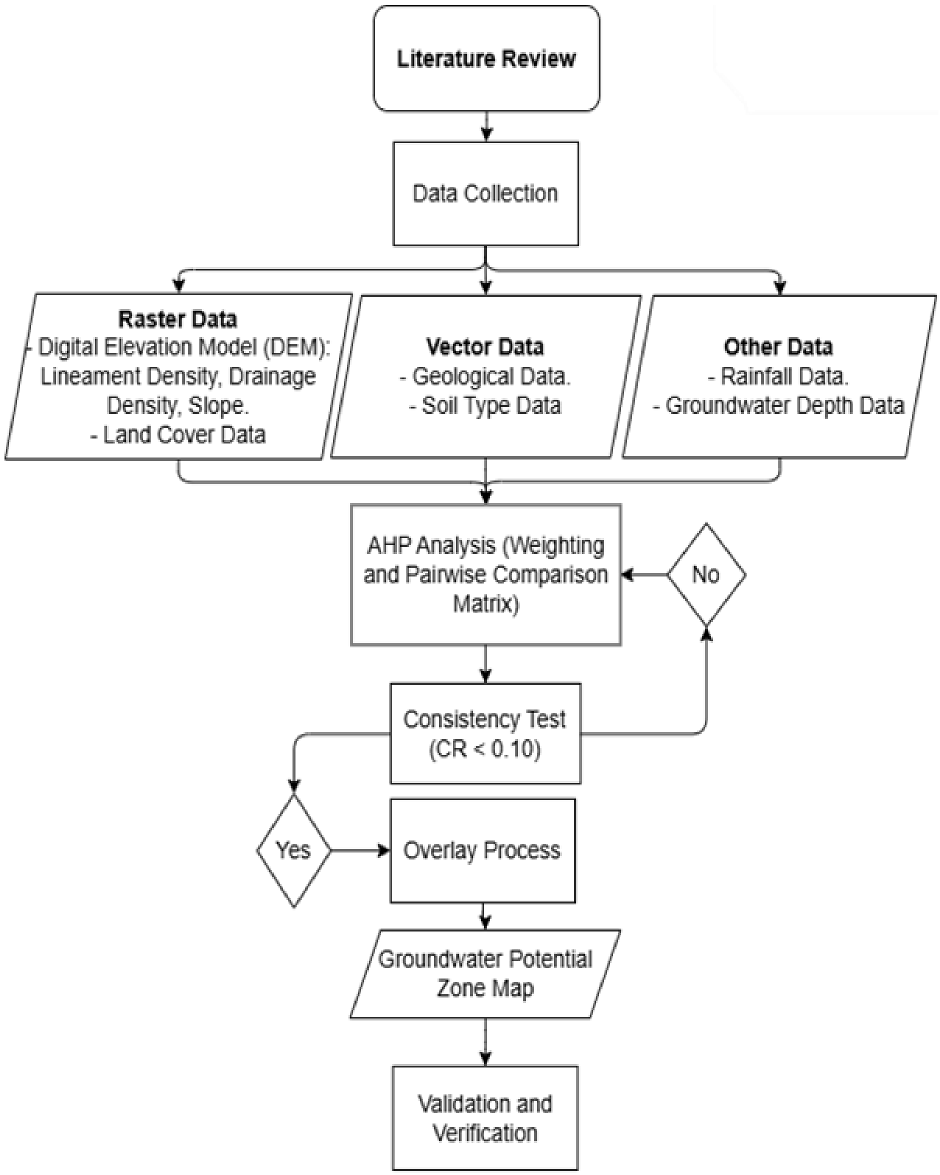

Figure 2. Research Flowchart

Data Analysis

The Analytic Hierarchy Process (AHP) as recommended by Saaty & Vargas (2012) is the most widely used and effective method in Multi-Criteria Decision Making (MCDM) for assigning weights to each parameter considered in the study. As suggested by Saaty & Vargas (2012), the following step-by-step procedure can be used to assign parameter weights:

a. The scale used ranges from a minimum of 1 to a maximum of 9.

b. A pairwise comparison matrix is then constructed, and the relative importance ratio scale values from 1 to 9 are entered. The matrix is then normalized by dividing each value in the column of the pairwise comparison matrix by the column sum.

c. In the third step, the weight of each parameter is calculated by dividing the row sum of the normalized pairwise comparison matrix by the number of parameters.

Table 2. Relative Importance Ratio Scale

Value	Meaning	Description
1	Equal Importance	Both parameters are equally important.
3	Slightly More Important	One parameter is slightly more important than the other.
5	More Important	One parameter is more important than the other.
7	Very Important	One parameter is strongly more important than the other.
9	Absolutely Important	One parameter is absolutely more important than the other.
2, 4, 6, 8	Intermediate Values	Represent intermediate values between two adjacent judgments for a given parameter.

Source: Saaty & Vargas (2012)

To verify whether the pairwise comparisons are consistent or not, a consistency check can be performed using the equations below. The Consistency Index (CI) can be calculated using the following equation, as described and provided by Saaty & Vargas (2012):

$$\mathbf{CI = (\lambda max - n) / (n - 1)}$$

Where CI = Consistency Index; λmax = maximum eigenvalue; n = number of parameters.

As suggested by Saaty & Vargas (2012), the maximum eigenvalue (λmax) of the pairwise comparison matrix can be computed through the following procedure:

2. Multiply each value in the unnormalized matrix by the parameter weight.
3. After obtaining the values, sum the results for each column to derive the weighted sum.
4. Then, divide the weighted sum by the parameter weight.
5. Calculate the average of the results obtained from the weighted sum divided by the parameter weight. This yields the maximum eigenvalue.

The Consistency Ratio (CR) can be computed using the following equation recommended by Saaty & Vargas (2012) to verify the consistency of pairwise comparisons:

$$\mathbf{CR = CI / RI}$$

Where CR = Consistency Ratio; CI = Consistency Index; RI = Random Index.

Table 3. Random Index

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9–10**
R.I	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45–1.49

Source: Saaty & Vargas (2012)

If the CR value is below 0.10, the pairwise comparison matrix is considered to have acceptable consistency. Conversely, if the CR value equals or exceeds 0.10, the pairwise comparisons indicate inadequate consistency, and the comparison process must be repeated until the CR falls below 0.10 (Saaty & Vargas, 2012). To map groundwater potential zones, the formula used is as follows: Parameters: LD CH GE DD LC S ST

The weight determination for each parameter in this study uses the Analytic Hierarchy Process (AHP) approach adapted from the study by Agegnehu Kitanbo Yoshe (2023). That study was selected as a reference because it shares similar regional characteristics, namely complex topography, volcanic geology, and high rainfall intensity, and uses the same parameters. Weight adaptation was carried out to obtain a rational representation of the relative contribution of each parameter in determining groundwater potential. Although there is potential for differences in local conditions such as lithological variations and aquifer properties, this risk was minimized through field validation and fitness analysis using the ROC Curve to ensure that the weights used can represent the actual conditions of the study area.

The ranking method (AHP) has been adopted to assign weights to each thematic layer. Groundwater potential is represented by values 1–3, where 1, 2, and 3 correspond to low, moderate, and high, respectively (Pratama & Aprilana, 2023).

RESULTS AND DISCUSSION

1) AHP Weighting and Groundwater Potential Parameters

a. AHP Weighting

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making method used to determine the weight of several parameters based on a priority scale (Saaty & Varga, 2012). In this study, AHP was applied to determine the weight of each parameter influencing groundwater potential in Batang Sub-district, Jeneponto Regency. Parameter selection was based on a literature review and the hydrogeological conditions of the study area. Thematic map parameters governing the groundwater recharge pathways include land use, soil type, drainage density, lineament density, rainfall, slope, and geology (Naeem et al., 2024). The seven thematic parameters influencing groundwater recharge zones were then analyzed pairwise to obtain priority weights in the AHP model, as shown in Table 4. The normalization matrix results and the final weight calculation for each parameter are presented in Table 5.

The weighting results show that lineament density has the highest value at 37%, indicating that fractures or faults in the study area strongly influence the potential presence of groundwater, as they often serve as primary pathways for subsurface water flow. The rainfall parameter ranks second with a weight of 30%, owing to its substantial role as the primary source of groundwater recharge. Geology ranks third with a weight of 14%, reflecting the influence of rock conditions on the capacity to store and transmit groundwater. Other parameters such as drainage density (7%), land cover (5%), slope (4%), and soil type (3%) also contribute, albeit at smaller percentages. Each remains relevant as it relates to infiltration and surface runoff.

For the consistency check of pairwise parameter comparisons, a consistency test was conducted, yielding CI = 0.12 and CR = 0.08. The CR value, which remains below the threshold of 0.10, indicates that the judgments used in the AHP method are consistent and suitable as a basis for the spatial analysis process (Saaty & Varga, 2012).

Table 4. Pairwise Comparison Matrix of 7 Parameters in the AHP Model

Parameter	KK	CH	GE	DD	TL	K	JT
Lineament Density	1	3	3	6	7	5	9
Rainfall	1/3	1	3	9	9	7	5
Geology	1/3	0	1	3	3	5	7
Drainage Density	1/6	1/9	1/3	1	2	3	4
Land Cover	1/7	1/9	1/3	1/2	1	3	1
Slope	1/5	1/7	1/5	1/3	1/3	1	2
Soil Type	1/9	1/5	1/7	1/4	1	1/2	1

Source: Yoshe (2023)

Table 5. AHP Model Normalization Matrix and Weights

Parameter	LD	RF	GE	DD	LC	S	ST	Sum	Weight	Weight (%)
LD	0.4372	0.612	0.3746	0.2988	0.3000	0.2041	0.3103	2.5374	0.3625	37
RF	0.1457	0.2041	0.3746	0.4481	0.3857	0.2857	0.1724	2.0164	0.2881	30
GE	0.1457	0.0680	0.1249	0.1494	0.1286	0.2041	0.2414	1.0620	0.1517	14
DD	0.0729	0.0227	0.0416	0.0498	0.0857	0.1224	0.1379	0.5331	0.0762	7
LC	0.0625	0.0227	0.0416	0.0249	0.0429	0.1224	0.0345	0.3514	0.0502	5
S	0.0875	0.0293	0.0250	0.0166	0.0143	0.0408	0.0690	0.2822	0.0403	4
ST	0.0486	0.0408	0.0178	0.0124	0.0429	0.0204	0.0345	0.2174	0.0311	3

Source: Yoshe (2023)

Note: LD = Lineament Density; RF = Rainfall; GE = Geology; DD = Drainage Density; LC = Land Cover; S = Slope; ST = Soil Type

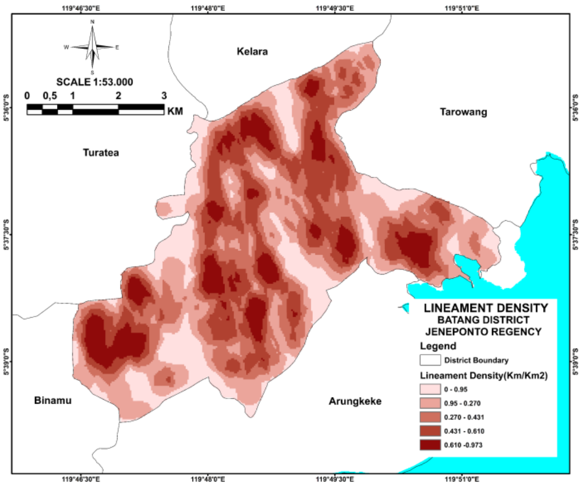

Figure 3. Lineament Density Map of Batang Sub-district

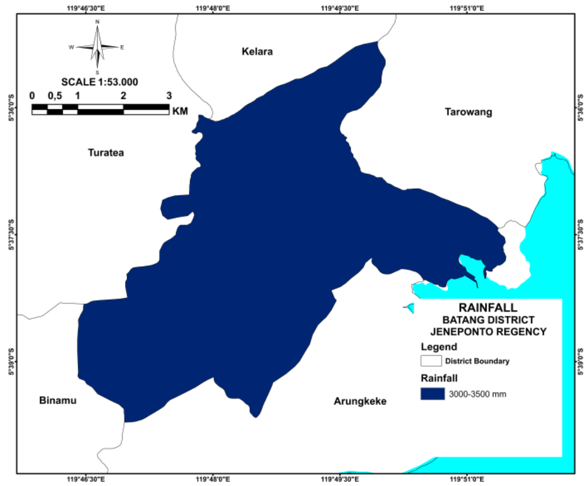

Figure 4. Rainfall Map of Batang Sub-district

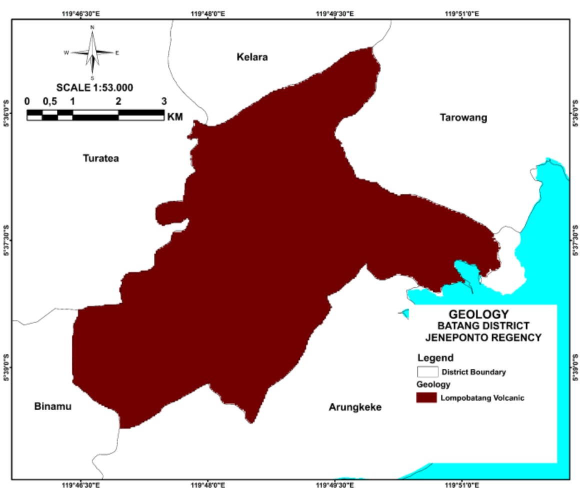

Figure 5. Geology Map of Batang Sub-district

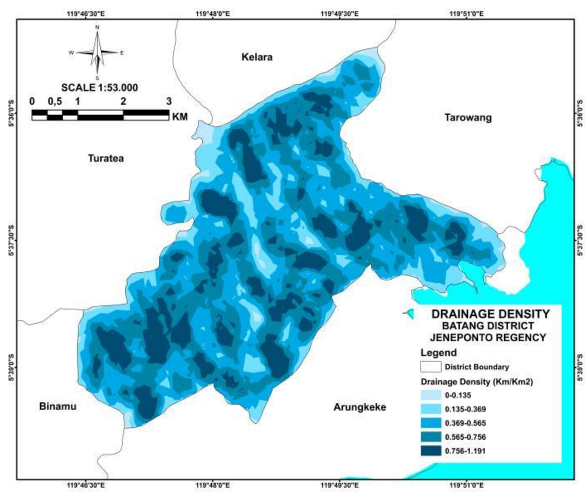

Figure 6. Drainage Density Map of Batang Sub-district

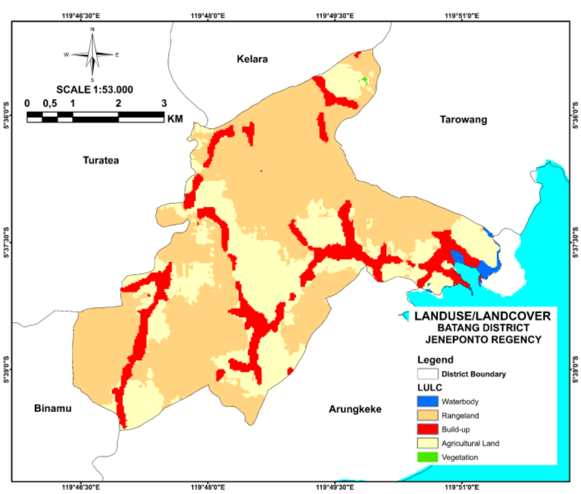

Figure 7. Land Cover Map of Batang Sub-district

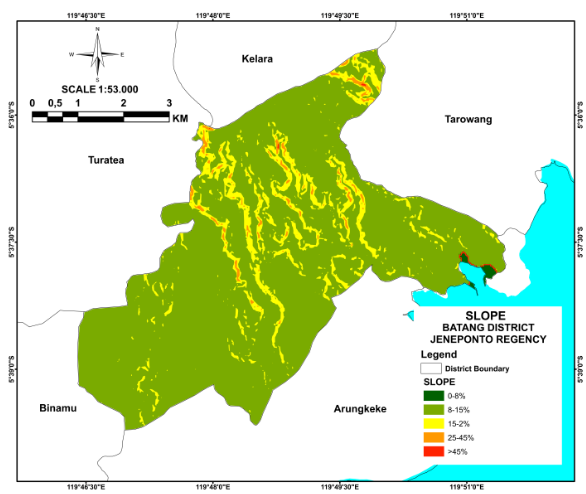

Figure 8. Slope Map of Batang Sub-district

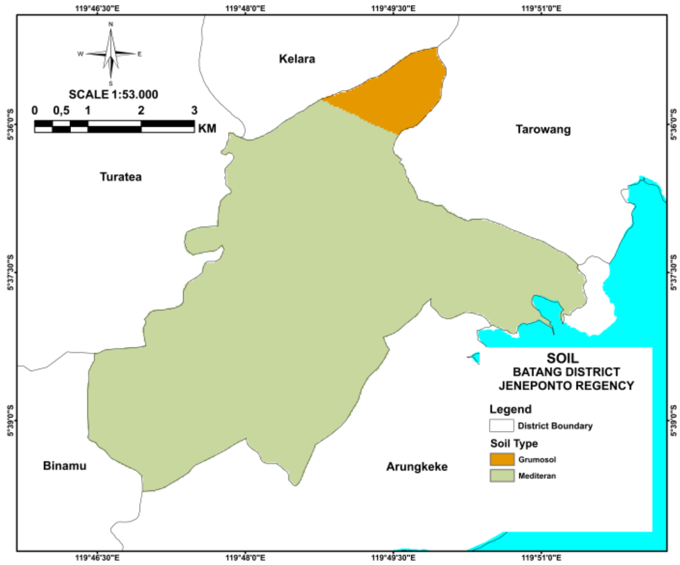

Figure 9. Soil Type Map of Batang Sub-district

b. Groundwater Potential Parameters

1. **Lineament Density Parameter**

Spatial analysis results show that most of Batang Sub-district has lineament density in the low to moderate category. The low category dominates, covering 897.03 hectares (26.18%), followed by the moderate category at 833.88 hectares (24.34%) and the good category at 772.22 hectares (22.54%). The very low category covers 562.38 hectares (16.41%), while the very good category covers only 360.83 hectares (10.53%). From this distribution, it can be concluded that the majority of Batang Sub-district has lineament density at the low to moderate level.

2. **Rainfall Parameter**

Based on rainfall data from 2024, all areas of Batang Sub-district fall within the high rainfall class, ranging from 3,000 to 3,500 mm per year. The area covered by this class reaches 3,420.10 hectares, encompassing 100% of the total study area. The rainfall map of Batang Sub-district is shown in Figure 4.

3. **Geology Parameter**

Based on the interpretation of the geological map obtained from the Department of Energy and Mineral Resources of South Sulawesi Province, the entire area of Batang Sub-district lies within the same rock unit, namely the Lompobattang Volcanic Rock. This rock type is classified into the “low” class. The geological map of Batang Sub-district is shown in Figure 5.

4. **Drainage Density Parameter**

Results shown in Table 6 indicate that the moderate class (0.369–0.565 km/km^2) dominates the study area, covering 1,084.35 ha (31.67%). The low class (0.565–0.756 km/km^2) and the good class (0.135–0.369 km/km^2) cover 28.41% and 21.89%, respectively. The very low class (0.756–1.191 km/km^2), which has the highest density values, covers 13.32% of the area. High flow density in the (0.756–1.191 km/km^2) class causes rainwater to flow more rapidly across the surface, thereby reducing infiltration and increasing surface runoff potential. The drainage density distribution map of Batang Sub-district is presented in Figure 6.

5. **Land Cover Map**

Based on ESRI Land Cover data from 2024, land cover in Batang Sub-district (Table 6) is dominated by open land covering 1,984.37 hectares, or 57.90% of the total area. This land generally has fairly good infiltration potential, provided it is not covered by impermeable materials. Agricultural land covers 985.97 hectares (28.77%) and supports infiltration. Conversely, residential areas covering 434.57 hectares (12.68%) have low infiltration potential because surfaces are largely covered by concrete and asphalt. Water bodies and natural vegetation such as shrubs or small forests cover very limited areas, each accounting for less than 1%. Although small in extent, these land cover types remain important for supporting infiltration at the local level. The land cover map is shown in Figure 7.

6. **Slope Parameter**

Classification results shown in Table 6 indicate that most of Batang Sub-district falls into the good category, with slope ranging from >8–15% and covering 2,979.15 hectares, or approximately 87.75% of the total area. This indicates that most areas have relatively gentle slopes, which support infiltration processes and reduce the risk of surface runoff. Areas in the moderate category (slope >15–25%) cover 362.17 hectares, or 10.67%, while the low category (slope >25–45%) covers 39.74 hectares (1.17%). The extreme slope category (>45%) covers only 3.83 hectares (0.11%), and the very good category (slope 0–8%) covers 9.97 hectares (0.29%). From these data, the majority of the area has a slope gradient considered safe and conducive to groundwater infiltration.

7. **Soil Type Parameter**

Based on data from the Food and Agriculture Organization (FAO) global soil map (Table 6), the majority of Batang Sub-district is dominated by Mediterranean soil, covering approximately 94.33 percent of the total area. Mediterranean soil is categorized as "moderate" in terms of water retention capacity. This soil type generally has a sandy to clay-loam texture and a relatively stable structure, enabling it to support the infiltration process well, particularly when undisturbed by compaction or erosion. The remaining approximately 5.67 percent of the area consists of grumosol soil, which is classified as "low" because it generally has a structure less conducive to water absorption, or is excessively clayey, thereby slowing infiltration. The soil type map is shown in Figure 9, which illustrates the distribution of each soil type in Batang Sub-district.

Table 6. Groundwater Potential Determining Parameters (Weight, Sub-class and Area Distribution)

No.	Parameter	Weight (%)	Sub-class / Range	Score	Area (Ha)	Percentage
1	Lineament Density	37	0 – 0.95 (Very Low)	1	562.38	16.41%
			0.95 – 0.270 (Low)	2	897.03	26.18%
	(km/km^2)		0.270 – 0.431 (Moderate)	3	833.88	24.34%
			0.431 – 0.610 (Good)	4	772.22	22.54%
			0.610 – 0.973 (Very Good)	5	360.83	10.53%
2	Rainfall (mm/year)	30	3,000 – 3,500 (High)	3	3,420.10	100%
3	Geology	14	Lompobattang Volcanic Rock (Low)	1	3,420.10	100%
4	Drainage Density (km/km^2)	7	0.135 – 0.369 (Good)	4	749.41	21.89%
			0.369 – 0.565 (Moderate)	3	1,084.35	31.67%
			0.565 – 0.756 (Low)	2	972.26	28.41%
			0.756 – 1.191 (Very Low)	1	455.95	13.32%
5	Land Cover	5	Water Body (Very Good)	5	21.62	0.63%
			Vegetation (Good)	4	8.45	0.25%
			Open Land (Moderate)	3	1,984.37	57.90%
			Agricultural Land (Low)	2	985.97	28.77%
			Settlement (Very Low)	1	434.57	12.68%
6	Slope (%)	4	0 – 8 (Very Good)	5	9.97	0.29%
			>8 – 15 (Good)	4	2,979.15	87.75%
			>15 – 25 (Moderate)	3	362.17	10.67%
			>25 – 45 (Low)	2	39.74	1.17%
			>45 (Extreme)	1	3.83	0.11%
7	Soil Type	3	Mediterranean (Moderate)	2	3,226.20	94.33%
			Grumosol (Low)	1	193.90	5.67%

Source: Analysis Results (2025)

2) Groundwater Potential Zone Map

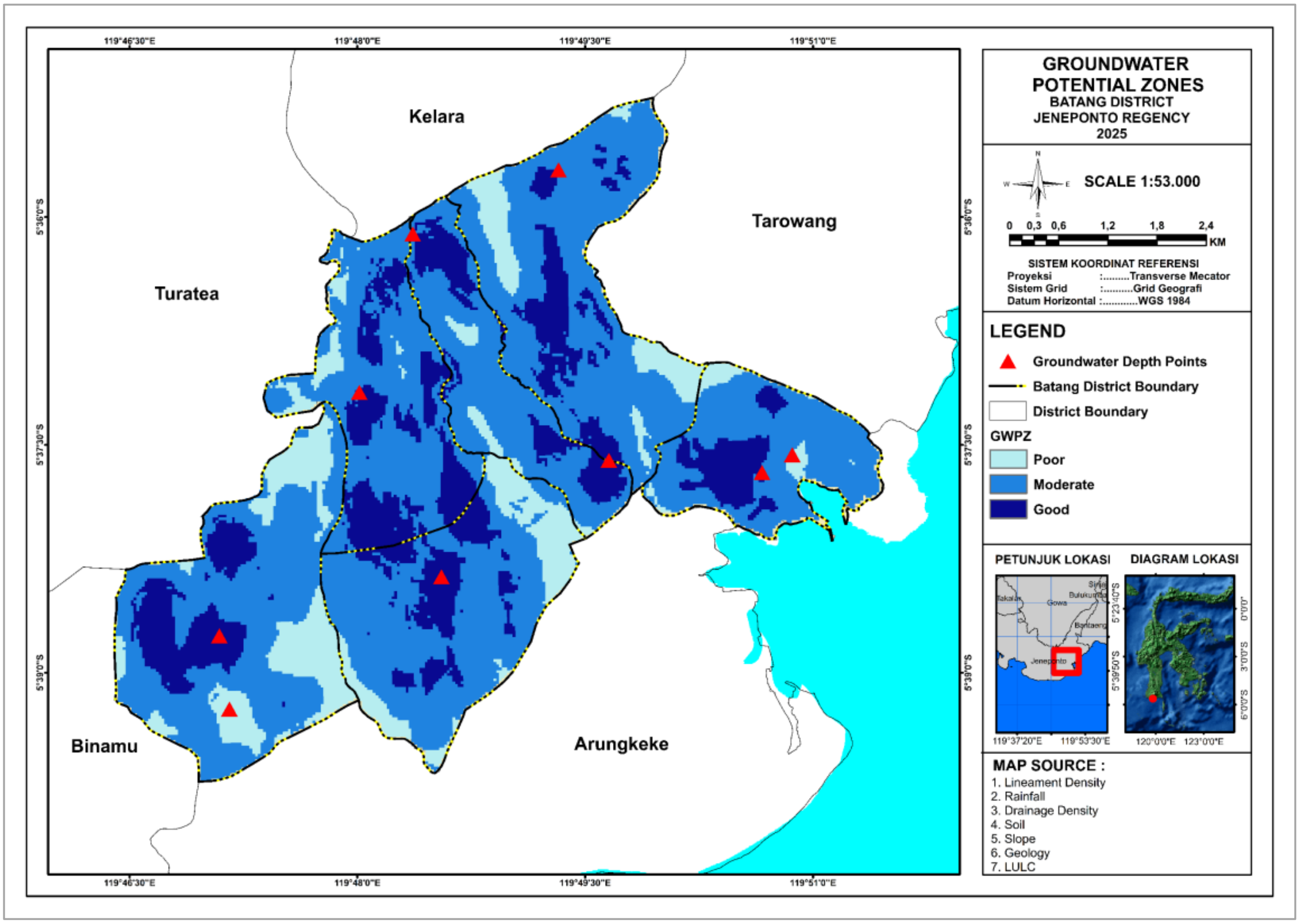

Figure 10. Groundwater Potential Zone Map of Batang Sub-district (2025)

Table 7. Groundwater Potential Zone Distribution in Batang Sub-district

No.	Category	Area (Ha)	Percentage (%)
1	Low	455.9788	13.53%
2	Moderate	2,226.87	66.07%
3	High	687.4663	20.40%

Source: Analysis Results (2025)

Based on the overlay results shown in Table 7, most of Batang Sub-district falls within the moderate groundwater potential zone, covering approximately 2,226 hectares, or about 66.07% of the total area. This indicates that most of the area has physical and environmental characteristics sufficiently supportive of water infiltration into the soil and storage beneath the surface. Factors such as relatively gentle slopes, agricultural land and open land as dominant land cover types, and the presence of Mediterranean soil all contribute to this outcome.

This moderate potential zone is distributed fairly evenly from west to east, with the greatest concentration in the central part of Batang Sub-district, indicating that most of the core area has reasonably good water infiltration capacity.

The high potential zone covers approximately 687.46 hectares, or 20.40% of the total area. These areas generally exhibit conditions highly conducive to groundwater infiltration, characterized by high lineament density (indicating numerous fractures or cracks in the rock), moderate to good drainage systems, and non-impermeable land cover types such as open land and agricultural areas. The high potential zone is distributed mainly in the central, northern, and northeastern parts of the sub-district.

The low potential zone covers 455.97 hectares, or approximately 13.53% of the total area. These areas are identified in the southern and southwestern parts of Batang Sub-district. This zone is believed to have several physical constraints, including steep slopes, soil types with limited water absorption capacity, and a dominance of impermeable land cover such as settlements.

This analysis produced a zonation map showing the spatial distribution of groundwater potential directions in Batang Sub-district, as seen in Figure 10. The map indicates that groundwater potential generally forms a central-to-northern pattern for the high zone, and a southwest-to-northeast pattern for the moderate zone, with the low zone distributed more narrowly in the southern and western peripheral areas

3) Validation and Verification of Groundwater Potential Results

Validation of the mapping results was conducted using groundwater depth data from nine observation points obtained from the Geological and Groundwater Division, Department of Energy and Mineral Resources of South Sulawesi Province. These observation points are distributed across several villages in Batang Sub-district, including Bugeng, Maccini Baji, Kaluku, Togo-Togo, Bontoraya, and Camba-Camba.

Each point is accompanied by geographic coordinates, village name, and actual groundwater table depth. This data was then compared with the groundwater potential zone classification results from the AHP model to determine correspondence. Of the nine validation points, eight showed agreement between actual conditions and the AHP mapping categories, while one point showed a discrepancy — at Bontoraya Village, the AHP classified the area as moderate potential, whereas actual data indicated shallow groundwater depth (high potential).

For measuring classification accuracy, statistical analysis was performed using the ROC Curve (Receiver Operating Characteristic) and AUC (Area Under the Curve) calculation. Groundwater potential categories were simplified into two classes: “high” (positive) and “not high” (moderate/low).

The ROC analysis results show:

1. True Positive Rate (TPR) = 83.3%
2. False Positive Rate (FPR) = 0%
3. AUC (Area Under Curve) = 0.92

An AUC value of 0.92 indicates that the AHP model has excellent classification performance, with strong capability to distinguish between high-potential and non-high-potential locations.

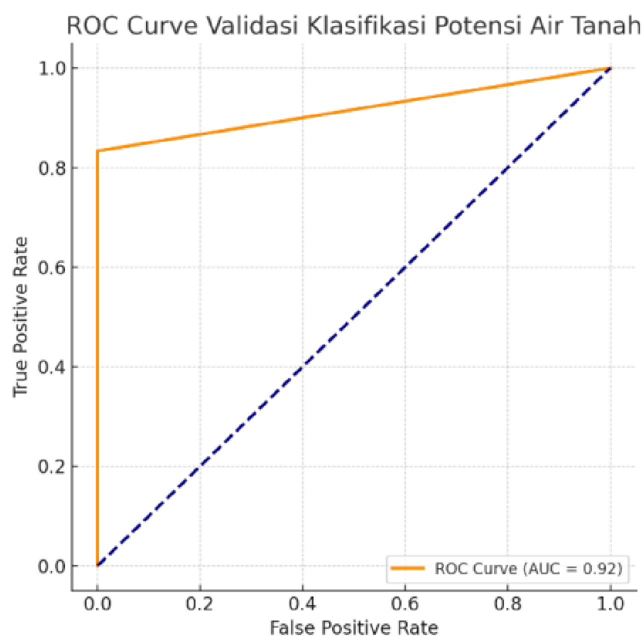

Figure 11. AHP Model Evaluation Based on ROC Curve Analysis

Table 8. Groundwater Potential Validation

No.	Longitude (X)	Latitude (Y)	Village Name	Groundwater Depth	Actual Category	AHP Mapping Result	Validation
1	119.847722	-5.626083	Bugeng	24 m	Low	Low	Match
2	119.78595	-5.653983	Maccini Baji	30 m	Low	Low	Match
3	119.806066	-5.601862	Kaluku	15 m	Moderate	Moderate	Match

No.	Longitude (X)	Latitude (Y)	Village Name	Groundwater Depth	Actual Category	AHP Mapping Result	Validation
4	119.827592	-5.626694	Togo-Togo	2.38 m	High	High	Match
5	119.822065	-5.594822	Bontoraya	4.17 m	High	Moderate	No Match
6	119.844403	-5.628033	Bugeng	2.27 m	High	High	Match
7	119.809214	-5.639475	Camba-Camba	2.28 m	High	High	Match
8	119.800208	-5.619233	Kaluku	2.48 m	High	High	Match
9	119.784845	-5.645947	Maccini Baji	3.36 m	High	High	Match

Source: Department of Energy and Mineral Resources, Geological and Groundwater Division; Analysis Results (2025)

Discussion

1. Groundwater Potential Parameter Results

The parameter with the highest weight in assessing groundwater potential is linear density, with a value of 37%. The results of the analysis in Batang District show that most of the area is in the low to moderate fracture density category, accounting for 26.18% and 24.34% of the total area, respectively. This condition indicates that the rock fracture structure is not densely distributed but still plays an important role in groundwater movement and infiltration, especially in areas with local fracture lines. The existence of these fractures is a potential water entry point, although the intensity is not particularly high. These findings are in line with the results of a study by Priya et al. (2022) in Barind Tract, Bangladesh, which showed that more than 55% of the study area was in the low to moderate linear density category (0.28–0.70 km/km^2). Although the density value is classified as low to moderate, this parameter was given the highest weight of 34.53% in the AHP model due to its crucial role in facilitating water infiltration into the soil through natural fracture pathways.

Rainfall is the second most important parameter with a weight of 30%, as it acts as the main source of groundwater recharge through the seepage process. The average rainfall in Batang District ranges from 3000–3500 mm/year, which is relatively high. Rainfall above >3000 mm/year is very high, resulting in an increase in soil moisture content (Rahmawati, 2024). Selvia et al. (2025) in West Sumbawa Regency showed that rainfall and hydrogeological conditions are key factors that affect groundwater availability in an area. Sajil Kumar et al. (2022) stated that areas with high rainfall, especially in tropical regions, have significant groundwater recharge potential.

Geological parameters ranked third in the assessment of groundwater potential with a weight of 14%. The Batang District is dominated by volcanic rocks from the Lompobattang Formation, such as volcanic breccia and tuff, which generally have hard physical properties and low permeability. However, the results of a geophysical study in the Camba-Camba area, Jeneponto Regency, which has similar geological conditions, show that these volcanic rocks still have the potential to become aquifers if they have sufficient fractures and porosity. (Arifianto et al., 2018). These findings indicate that although the geological conditions of the study include low permeability and hard properties, other parameters such as Linear Density (37%) show that secondary structures (fractures) play an important role in groundwater recharge.

The drainage density parameter with a weight of 7% shows that most of the Batang District is in the moderate class (31.67%), followed by the low class (28.41%) and good class (21.89%). This distribution shows that the surface flow network in the study area is not too dense, so that groundwater infiltration is still possible. In a study by El-Bagoury (2025), it is stated that areas with low drainage density are more conducive to groundwater infiltration and recharge, compared to areas with high density which are more prone to surface runoff.

Slope is given a weight of 4% because it affects the speed of surface water flow. Gentle slopes tend to support the infiltration process, while steep slopes encourage rapid runoff. Most of the Batang District is located on a slope of 8–15%, which is classified as moderate and supports infiltration. This finding is reinforced by the results of a study by Zewdie et al. (2024) in the upper Chemoga region of Ethiopia, which shows that areas with gentle to moderate slopes (≤15%) contribute to the groundwater potential zone because they allow for greater infiltration. In addition, a study by Uc Castillo et al. (2022) states that slope has a negative effect on groundwater potential; the steeper the slope, the lower the infiltration potential due to increased runoff rates.

Land cover with a weight of 5% also affects the water infiltration process. Land covered with natural vegetation and agriculture is able to retain water longer and increase the infiltration rate. In Batang District, agricultural land and vegetation dominate over impervious land cover such as settlements and water bodies. These findings are in line with a study by Agussalim and Rizal (2021) in Jeneponto Regency, which used geophysical methods to identify shallow aquifer zones. The results show that areas with vegetation cover and agricultural land, particularly in Arungkeke and Rumbia subdistricts, indicate the presence of aquifers, especially in zones with good soil permeability. This reinforces the fact that vegetative land cover not only increases infiltration but also correlates with high groundwater potential.

Soil type, although only accounting for 3%, still contributes to water retention capacity. The dominant soil type in this region is Mediterranean soil (94.95%), which is known to retain water well and support the infiltration process. This condition is in line with data from the Jeneponto District BPS (2023), which notes that Mediterranean soil is widespread in Batang District, along with the existence of topography and parent rock materials that support its formation. Research in Lamongan Regency by Hafidh et al. (2022) shows that Mediterranean soil is able to store water better than grumusol soil. Research by Ameilia (2018) in Pematang Village, South Lampung, shows that soil type conditions affect the quality and storage capacity of shallow groundwater.

2. Groundwater Potential Zone Results

The results of groundwater potential zone mapping show three classes: low, medium, and high. The medium potential zone is the dominant class, covering an area of 2,226 hectares or about 66.07% of the total area of Batang District. This zone reflects areas with conditions that are quite conducive to the infiltration process, such as gentle land slopes, a moderate drainage system, and Mediterranean soil types with moderate absorption capacity. Its distribution appears to extend from west to east, particularly dominating the central part of Batang District.

Furthermore, the high potential zone covers approximately 687.46 hectares (20.40%). These areas are characterized by high linear density, indicating numerous rock fractures, as well as the dominance of non-impermeable land cover such as open land and agricultural areas. Spatially, this zone is spread across the northern, central, and northeastern parts of Batang District. These findings are in line with the results of a study by Shinde et al. (2024), which shows that areas with high geological fractures and medium-textured soils have higher groundwater potential because they support infiltration.

The low potential zone covers an area of 455.97 hectares (13.53%). This zone is spread across the southern and southwestern parts, which generally have steeper topography, denser drainage, and are dominated by impervious land cover types such as residential areas or built-up land. These factors directly inhibit the infiltration process and increase surface runoff. This is in line with the results of a study by Alemu & Zelalem (2024), which states that areas with steep slopes and built-up land cover tend to have low groundwater potential.

In general, the distribution of groundwater potential shows that the high zone is more concentrated in the central to northern regions, reflecting geological and geomorphological conditions that support infiltration. The medium zone spreads from the southwest to the northeast, while the low zone tends to be located in the southern and western peripheries.

3. Validation of Mapping Results

Validation of the mapping results using nine observation points shows that the AHP approach in groundwater potential mapping provides excellent classification results. Eight of the nine points show consistency between the classification results and the actual conditions in the field. Meanwhile, one point in Bontoraya Village showed a difference between the model results and the observation data. This is thought to be due to local variations that were not fully detected by the parameters used, such as small-scale changes in land cover, more complex soil characteristics, and possible location shifts due to the conversion of coordinates from DMS (Degree Minute Second) to DD (Decimal Degree) format.

Statistically, the model's performance was evaluated using a ROC curve and produced an AUC value of 0.92. This is reinforced by a study by Shinde et al. (2024), which used the AHP method to map groundwater potential in semi-arid areas in India and obtained an AUC of 0.93, demonstrating the consistency of this method's effectiveness in various conditions. Previous studies have reported lower AUC values for the AHP method, such as a study in the North Shoa Zone (Ethiopia) which reported an AUC of 0.89, which is still categorized as "good" (Alemu & Zelalem, 2024).

This study makes an important contribution to mapping groundwater potential zones by integrating the AHP and GIS methods at the subdistrict level. These findings can also be used as a reference in spatial planning, water resource management, and drought risk mitigation in drought-prone areas such as Batang Subdistrict.

CONCLUSSION

This study mapped the groundwater potential in Batang District using the Analytic Hierarchy Process (AHP) method based on seven parameters, namely slope, drainage density, linear density, land cover, rainfall, soil type, and geology. Of these seven parameters, linear density received the highest weight of 37%, indicating that rock fracture pathways play a significant role in facilitating water infiltration into the soil. Conversely, soil type received the lowest weight of 3%, but still contributed because it affects the ability to store and release water on the surface layer.

The spatial analysis results show that there are three groundwater potential zones, namely: a high potential zone covering an area of 687.47 ha (20.40%), a medium potential zone covering an area of 2,226.87 ha (66.07%), and a low potential zone covering an area of 455.98 ha (13.53%). The medium potential zone is the most dominant category, which generally has a combination of gentle slopes, vegetation cover, and Mediterranean soil types. The high potential zone is located in areas with high straightness density and high rainfall, while the low potential zone is scattered in areas with steep slopes, residential land cover, and dense drainage.

Validation of nine observation points showed that the AHP classification results had a high level of accuracy between the results and actual groundwater depth data. Further statistical analysis through the ROC Curve produced an AUC value of 0.92, indicating that the AHP model has excellent classification capabilities in distinguishing between high and low potential zones.

The limitations of this study are mainly related to the limited number of validation points and the use of medium-scale spatial data, so that local variations such as small land cover changes or micro-hydrogeological characteristics are not fully described.

For further research, it is recommended to add validation points through more detailed field surveys, as well as the integration of other methods such as geoelectric or machine learning-based approaches. These efforts will improve the accuracy of mapping and produce more precise information to support sustainable groundwater resource management.

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