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THE USE OF GEOGRAPHIC INFORMATION SYSTEM (GIS) AND REMOTE SENSING (RS) FOR POTENTIAL UNCONFINED GROUNDWATER IN STRUCTURAL AND VOLCANO LANDFORMS

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Abstract. The Northern Bandung area covers two landforms, namely volcano and structural landforms. Unconfined groundwater has become the water source for local people's daily needs in both landforms. It is necessary to map the potential unconfined groundwater for both volcano and structural landforms due to the significant role of springs for the local people living in those areas. This research aims to map the unconfined groundwater on the volcano and structural landforms. This study employed the approaches of Analytical Hierarchy Process (AHP), Geographic Information System (GIS), and Remote Sensing (RS) using the variables of lineament density, rainfall, slope, and Topographic Wetness Index (TWI), hydrogeology, drainage density, and land use. The result shows that each variable has the Consistency Ratio (CR) below 0,1, resulting in consistent research variables and appropriate for discussion. The classification of the potential groundwater is divided into three categories: low, medium, and high. The survey validation finds that 147 springs spread at 86 high lands, 55 medium lands, and six lowlands. This model can be an alternative to map the potential unconfined groundwater in both volcano and structural areas.

Keywords: Geography Information System, Remote Sensing, groundwater.

Introduction

Unconfined groundwater is a water source supply to fulfill the needs of agriculture, drinking water consumption, and domestic and other daily needs in the Northern Bandung area. This area is on a volcanic-shaped land; thus, the water needs are from the unconfined groundwater. The volcanic-shaped land affects the existence of unconfined groundwater from its hydrogeology conditions (Aiuppa et al., 2003). Unconfined groundwater interacts with volcano activities (Favier et al., 2008), causing the frequent presence on the volcano-shaped land, which is usually fresh (Dianardi et al., 2018). Unconfined groundwater will be essential for Bandung people (Maryati et al., 2022), especially in the Northern area.

Groundwater distribution should be further identified for the sustainability of people's lives. The more settlements grow, the more populated the people will be, making the need for water increase (Hargono et al., 2014). The condition of the volcano-shaped land in the northern part of Bandung is adjacent to the structural-shaped land called the Lembang Fault. The stability of volcanic lands will affect the water stream variation and increase the seismic activity (Saar & Manga, 2003). This condition indicates the abundant distribution of unconfined groundwater in the Northern Bandung area. The groundwater identification will constantly interact with climatology, land shapes, geology, hydrology, and hydro ecology (Sophocleous, 2002).

Groundwater modeling has frequently been done using the Geographic Information System (GIS) technology in the volcano area. The SIG approach is capable of modeling the groundwater that is based on the parameters associated with groundwater existence, such as drainage density, slope, lineament density (Doke et al., 2021), rainfall, soil, geomorphology, geology (Tamiru & Wagari, 2021), and hydrological aspect, Land Use Land Cover (LULC) (El-Hadidy & Morsy, 2022). Furthermore, several lithology factors indicate groundwater fields' existence (Khakim et al., 2014). The Northern Bandung area has various land surface characteristics since it lies in the volcano area

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traversed with structural fields, making the SIG modeling proper to apply in this area.

Numerous models and parameters are used to map groundwater. A fuzzy analysis was done to detect the existence of groundwater in the volcano and structural areas with a good result in the Garut basin, Indonesia (Ihsan et al., 2020). Electrical resistivity soundings (ERS) can identify the groundwater on the alluvial surface in the Porali river, Pakistan (Mahmud et al., 2022). The Analytical Hierarchy Process (AHP) approach is regularly made in the potential groundwater pieces of literature by modifying the weight and the thematic parameter score. The AHP and Frequency Ratio (FR) models have been conducted in a vast area from the mountains to beaches in central Antalya, the southwestern part of Turkey (Ahmadi et al., 2021). The AHP approach can also be combined with the Geographic Information System (GIS) approach, which was done in Southern Western Ghats, India (Arulbalaji et al., 2019), Kancheepuram District, Tamilnadu, India (Saranya & Saravanan, 2020), and Muga Watershed, Abay Basin, Ethiopia (Melese & Belay, 2022).

This study aims to identify the groundwater potential using the approaches of AHP, GIS, and Remote Sensing (RS) in the volcanic area. Commonly, the groundwater review rarely uses Topographic Wetness Index (TWI) parameter, though, in this study, TWI becomes an additional thematic parameter to other parameters such as lineament density, rainfall, slope, and Topographic Wetness Index (TWI), hydrogeology, drainage density, dan land use. TWI has a linear correlation to the soil depth, the under-surface saturation, and the soil-bedrock caused by the rainfall (Liang & Chan, 2017), so it influences the groundwater's existence. Several approaches to groundwater potential with the TWI parameter are fuzzy analysis (Ihsan et al., 2020), ParFlow and Model Complexity Reduction Approach (MCRA), and Model-based wetness indices (MWIs) (Grabs et al., 2009).

1. Methods

The research location is in the Northern Bandung area (KBU), West Java province, Indonesia. Based on an analysis, the area of KBU is 389598 km^2, covering four cities and one regency: Bandung City, West Bandung Regency, Bandung Regency, and Cimahi City. According to the local government policy, the KBU borders are based on the ecoregion functions and environment. Taken from the data of DEMNAS KBU, it has the elevation to mean sea level of 728 MASL – 2202 MASL (Figure 1).

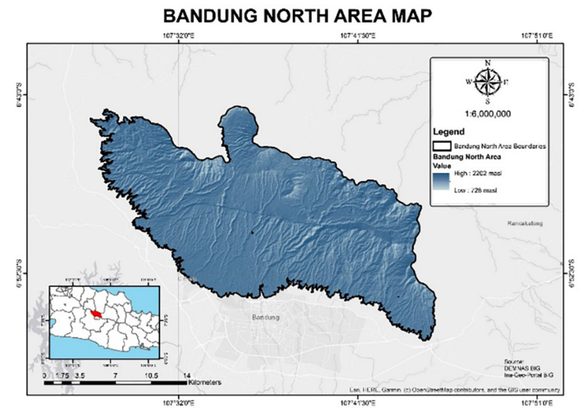

Figure 1. Research area

This study used the approaches of Analytical Hierarchy Process (AHP), Geographic Information System (GIS), and Remote Sensing (RS). The parameters used were lineament density, drainage density, land use, slope, rainfall, Topographic Wetness Index (TWI), and hydrogeology. GIS was used for the modeling of groundwater parameters. Meanwhile, RS was used for data extraction from the satellite images, and the AHP was used to model the entire parameters in identifying the groundwater potential.

1.1. Lineament density

Lineament density became one of the variables in groundwater identification because groundwater usually exists in the structural area. The more dense a lineament is, the more potential the groundwater will be (Epuh et al., 2020). Lineament can be extracted from Digital Elevation Model (DEM) data (Saint Jean Patrick Coulibaly et al., 2021). Lineament is obtained from DEMNAS that is accessible freely through https://tanahair.indonesia.go.id/demnas/#/, which then was analyzed using PCI Geomatics (Ihsan et al., 2020). Lineament density was analyzed using ArcGIS (Al-Shabeeb et al., 2018) with the following formula:

$$LD = \frac{\sum_{i=1}^{i=n} Li}{A}. \quad (1)$$

The above formula describes that the LD is, Li is the total length of lineament, whereas A is the width of the studied area.

1.2. Drainage density

Drainage density is a part of the existence of groundwater. The more loose a drainage is, the more potential the groundwater is because the water will infiltrate into the soil (Razavi-Termeh et al., 2019). A very dense water drainage area will be a run-off down to the drainage (Yildiz, 2004). Drainage density can be calculated using the following formula Horton (1932):

$$d = \sum_{i=1}^{n} Di / A \ \left(\text{km}^2\right). \quad (2)$$

The formula describes that d is the river density (km/km^2), Di is the whole length of the river (km^2), and the identification coverage. The drainage was extracted using DEMNAS and then was analyzed using the arc hydro tools (Oikonomidis et al., 2015).

1.3. Land use

In this study, land use has become one of the parameters because it is assumed that the developed area will give two opportunities for the water surface to experience run-off or absorb into the soil. In developed regions, residences and specific land use such as the water fields will become run-off and go down by the topography condition. According to its permeability, it will absorb several land uses, such as water forests. The water catchment in a non-developed area fulfills the groundwater (Tamiru & Wagari, 2021).

The land use study can be extracted using the Remote Sensing (RS) approach to classify the earth's surface (Moodley et al., 2022). The land use data were processed from the sentinel-2B image from https://earthexplorer.usgs.gov/ on June 23rd, 2022. The sentinel-2B data was formed into a land use map using the supervised classification by an adjusted presentation to the scale of KBU. Visualized land use parameters were forests, moorlands, plantations, shrubs, grasses, fields, water bodies, settlements, and rocky grounds.

1.4. Slope

Water will go down following the gravity direction and slope conditions from the uphill to the downhill (Bhadran et al., 2022). Groundwater is usually located on a flat slope or a lower slope. The slope can be constructed using the data from DEM (Sahu et al., 2022). In this study, the DEM data used was from DEMNAS. The slope was analyzed using ArcGIS Software. The slope classification used was 0–2% flat, 3–7% gentle, 8–13% gentler, 14–20% slightly steep, 21–55% steep, 56–140% very steep, and >140% very steep (van Zuidam, 1985).

1.5. Rainfall

Rainfall is one of the primary sources of groundwater (Hussain et al., 2022). Rain will be the groundwater source if it falls on the ground surface with high absorption capacity toward the aquifer (Andualem et al., 2021). The higher an area's rainfall, the more potential for the existence of groundwater will be assumed. The ArcGIS software mapped the rain using Inverse Distance Weighted (IDW) technique. IDW is one of the spatial approaches to describe the rainfall distribution that usually possesses a good accuracy, yet, the results depend on the quality of the rain data and posts (Chen & Liu, 2012). IDW is a spatial approach with a high correlation compared to other spatial algorithms (Ihsan et al., 2021). The rainfall used had four rain posts ranging from 2004 to 2021.

1.6. Topographic Wetness Index (TWI)

Topographic Wetness Index describes the water saturation area in a location, which identifies the variety of ground materials and the hydrology process (Grabs et al., 2009). TWI is highly correlated to the soil moisture (Kopecký et al., 2021), so it can be assumed with the groundwater potential. The higher the TWI score is, the lower the slope will be (Ghorbani Nejad et al., 2017); meanwhile, the higher the groundwater potential is (Ihsan et al., 2020). The TWI uses the following calculation below:

$$TWI = In\left(\frac{\alpha}{\tan\beta}\right). \tag{3}$$

The formula describes that α is the area of the non-slope contributing site and β is the slope angle. The study of TWI was analyzed using the SAGA GIS software with the model of digital elevation data in DEMNAS.

1.7. Hydrogeology (aquifer)

The aquifer is a hydrology component that contains groundwater whose characteristics are based on its formation process (De Vargas et al., 2022). In this study, the aquifer data was obtained from the Geology Agency, which has information about aquifers with low and local productivity, the aquifer with a wide distribution, local productive aquifers, and scarce groundwater areas. The more effective and broader the distribution, the more ability the aquifer has to contain and the more potential it has to have high groundwater. The aquifer system benefits from containing groundwater fields (Sedghi & Zhan, 2022).

1.8. Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) approach was employed to identify the potential of unconfined groundwater in the volcano landform area. This approach is a mathematical model from the multi-criteria decision mapping approach (Saaty, 1977). The steps in AHP consist of hierarchy construction, priority determination (scores and indicator weighing), and consistency index determination (Amponsah et al., 2022). The formula of the consistency index is the following:

$$CI = \frac{\lambda\max - n}{n-1}; \quad CR = \frac{CI}{RI}. \tag{4}$$

The formula describes *CI* as the consistency index, *CR* as the consistency ratio, and n as the number of variables. *RI* is the Random Consistency Index obtained from the matrix table (Table 1). If the value of $CR <= 0.1$ thus, the matrix is consistent, and if the value of $CR > 0.1$ thus, the matrix is inconsistent. Consistency is the equivalent score weighing that is given between the criteria.

Table 1. Random Consistency Index (source: Saaty et al., 2001)

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The score and weighing results in each calculation of the AHP approach indicator would be processed using the modeling in GIS to determine the potential of unconfined groundwater. The application used is ArcGIS. Each score would be formed in a data raster with values according to the AHP calculation. It would result in the potential mapping of unconfined groundwater with a low range of classification, medium, and high. The map would be validated

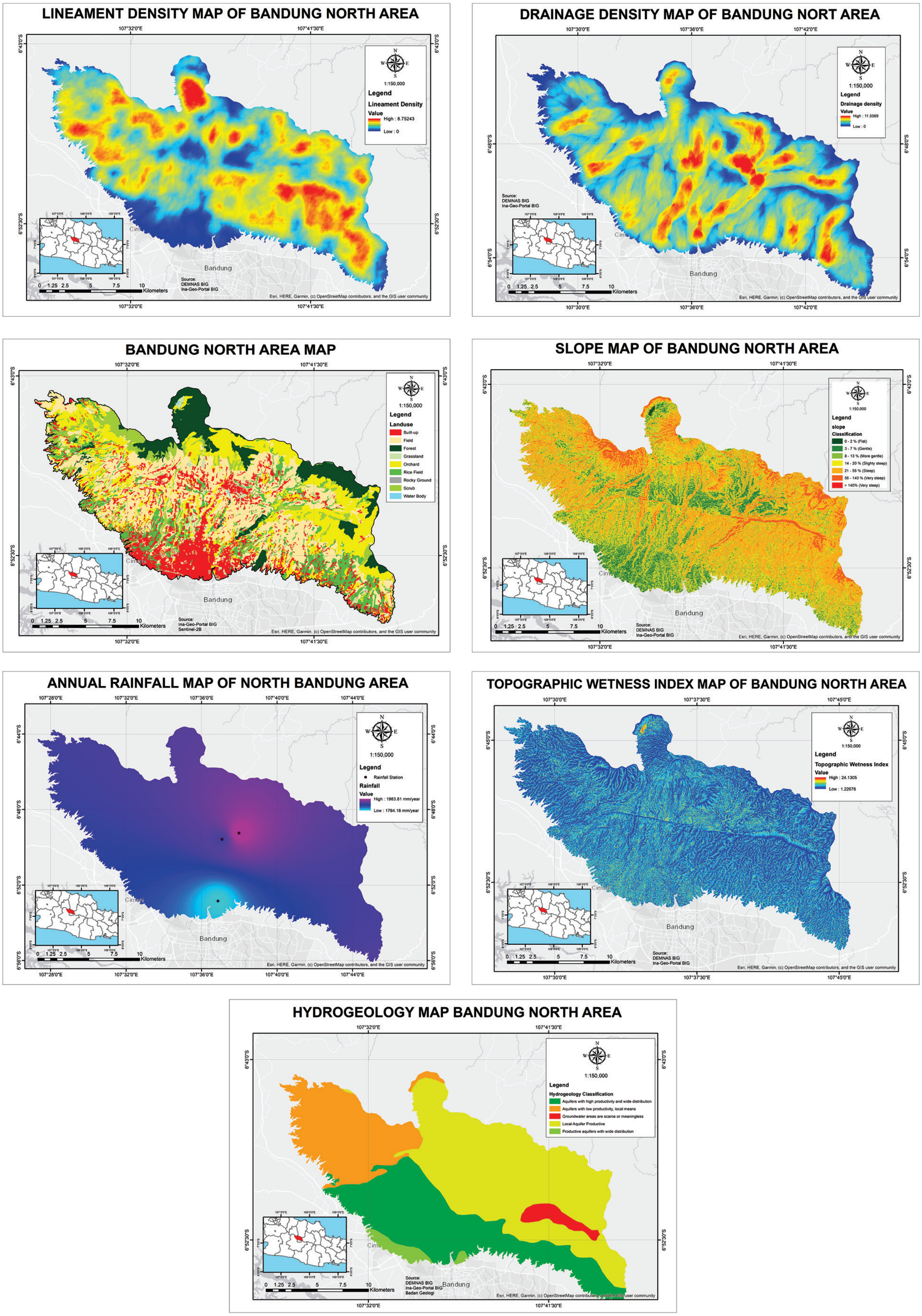

Figure 2. Variable Groundwater Map

using the field survey method. Each category would identify the existence of unconfined groundwater, which then would be adjusted to the premade maps. The unconfined groundwater would be plotted according to the coordinate locations using the Global Positioning System Geodetic.

2. Results

2.1. Lineament density

From the extraction results of DEMNAS, there was 2.747 lineament with a length of 0.35 m s/d 3308.5 m. The total length of the lineament was 1 544 485.27 m or 1544.48 km. The lineament in this study formed a ridge from each plateau which extends based on the earth's surface. According to the manual calculation, the value of the lineament density was 3.96 km^2. The spatial analysis showed that the range of the lineament density was from 0 s/d 8.75243 km^2. The average lineament density from the software was 3.8 then. It had a value that was almost similar to the manual calculation. The standard deviation in this lineament density study was 1.75. In the raster information, there were 4034 columns and 2768 rows.

The location of the lineament tends to be even across the KBU. The geology map of Lembang found that the structural form extends from the east to the west. In KBU, two significant landforms are found: volcano and structural landforms. The source of the water in the volcano and structural areas is springs, where in this location, there are many springs that the people use for their daily use. The lineament has solid characteristics indicating the potential of springs' existence.

2.2. Drainage density

In KBU, the drainage is divided into five ordos based on the direction from the software using the *Strahler* approach. The extraction result showed that the first ordo has a length of 488.15 km, the second ordo is 279.42 km long, the third ordo is 102.98 km, the fourth ordo's length is 41.04 km, and the fifth ordo is 18.64 km long. The whole length of the drainage is 930.22 km. The drainage in the volcano or structural landform areas has many ordos so that the length of the river is adjusted to the number of the ordos in the research location.

The calculation shows that the drainage density in KBU ranges from 0 to 11,5569 km^2. The drainage density area spreads to the research location and is most visible in the middle part of KBU. The drainage density is associated with the groundwater's existence; when the rain falls on the surface of the solid stream thus, the water will fall into the river. Meanwhile, the water will infiltrate as recharge groundwater in the open stream area.

2.3. Land use

The Land Use in the KBU area was visualized using the mapping scale. The map scale would adjust the information created. In the research location, there are nine kinds of land use: the body of water, shrubs, forests, plantations, moor lands, settlements, grasses, fields, and rocky grounds. Most of the land use area in KBU is dominated by moor lands (11865.25 ha) and plantations (9297 ha). The KBU area is a horticultural plantation area on a plateau, making the soil characteristics easy to absorb and recharge groundwater.

The smallest area of land use in KBU is the rocky grounds. The rocky ground areas are the Lembang fault that rose to the surface due to tectonic activities. The area is called Gunung Batu by the local people, and its width is 3.9 ha. This area is one of the tourist places. Further, this area is resistant to water, so the water in this area becomes run-off due to the topography conditions. The settlement area in the KBU causes rainfall to run off and streams down along the drainage and the topography condition.

2.4. Slope

The KBU has a variety of slopes; all types of slopes, according to van Zuidam (1985), exist in this area. Based on the analysis, the slope ranges from 0% to 165.072%, with an average of 25.68% and a deviation standard of 17.24%. The slope in this research is dominated by the steep type for 21–55%, as wide as 18 573.74 ha. The smallest area of the slope is the very steep type for >140%, as wide as 1.83 ha. This is the characteristic of the volcano and structural landforms. In both landforms, some ridges and valleys have steep and very steep slopes. The groundwater is usually found on gentle slopes because the water flows according to gravity. Specifically, the flat slope ranges from flat 0–2% for 436.84 ha, the gentle slope ranges from 3–7% for 4121.13 ha, gentles slopes range from 8–13% for 5862.34 ha, the slightly steep ones 14–20% for 7369.14 ha, and the very steep ones for 56–140% 2593.77 ha.

2.5. Rainfall

On average, the rainfall in the KBU area was 1764.18 mm/year – 1983.81 mm/year from 2004–2021. The rainfall was analyzed based on the calculation from the four rain posts spread in the research location. The mean values in every post are: Kayu Ambon Post 1983.81 mm/year, Lembang Post 1894.52 mm/year, and Rancaekek Post 1904.76 mm/year. The rain in the KBU area is relatively big because it is located in a mountainous area. The rain that usually falls is orographic rain which generally falls in mountainous regions. The potential of springs in the highest rainfall area occurred in Lembang Post for 4937.76 mm/year in 2016.

2.6. Topographic Wetness Index (TWI)

The KBU has a minimum and maximum score on the Topographic Wetness Index of 1,22676 and 24,1305, respectively. The average TWI is 5,798, with a deviation standard of 1,892. From the analysis, 4064 columns and 2813 rows of TWI values reflect the topography conditions in the volcano- and structural-shaped areas. The high TWI value shows flat or basin conditions making

Table 2. Analytical hierarchy procces value

Variables	Variable Values	Classification	Value class	CI	CR
Rainfall	0.311469061	High	0.588888889	0.035185	0.060664
		Moderate	0.251851852		
		Low	0.159259259		
Hydrogeology	0.286979265	High productivity and wide distribution	0.422091302	0.078877	0.070426
		Productive with wide distribution	0.252913813		
		Local productive aquifer	0.154130685		
		Low Productivity	0.106026381		
		Scarce groundwater area	0.06483782		
Lineament density	0.117106414	High	0.588888889	0.035185	0.060664
		Moderate	0.251851852		
		Low	0.159259259		
Slope	0.099598816	0–2% (Flat)	0.321219782	0.052181	0.039531
		3–7% (Gentle)	0.220672705		
		8–13% (Gentler)	0.164242942		
		14–20% (Slightly steep)	0.109481399		
		21–55% (Steep)	0.075715273		
		56–140% (Very steep)	0.062109831		
		>140% (Very steep)	0.046558068		
Topographic wetness index	0.093767912	High	0.588888889	0.035185	0.060664
		Moderate	0.251851852		
		Low	0.159259259		
Drainage density	0.054594473	High	0.588888889	0.035185	0.060664
		Moderate	0.251851852		
		Low	0.159259259		
Land Use	0.036484059	Forests	0.211093082	0.006787	0.004681
		Moorlands	0.211093082		
		Plantations	0.124186892		
		Shrubs	0.112490985		
		Grasses	0.112490985		
		Fields	0.060213747		
		Body of Water	0.060213747		
		Settlements	0.054108741		
		Rocky Grounds	0.054108741		

the areas associated with the existence of groundwater. The TWI value in an elevated area is water accumulated is assumed to be the recharged groundwater. The TWI in the KBU describes the water absorption condition from the topography of the volcano and structural landforms.

2.7. Hydrogeology

Hydrogeology in this study is the aquifer condition whose data was obtained from related instances. The hydrogeology condition is dominated by the local classification of the productive aquifer as wide as 178.17 km^2. The aquifer is located in the northern and eastern parts of the research area. The smallest area of the productive aquifer has a distribution scope of 8.16 km^2. Commonly, the volcano- and structural-shaped regions have a good aquifer. However, it has a very deep aquifer in a high place because it is covered with thick solum, so the groundwater usually found on the plateau is the springs. In shallow areas like valleys or near flat rivers, groundwater can be obtained from drilling.

2.8. Analytical Hierarchy Process (AHP)

From the Consistency Ratio (CR) calculation, the value was obtained to be below 0.1, meaning that each variable in this research was consistent. The variables were eligible to use in the study. The CR value is constant if it is below 10% or 0.1. Consistency is where an equal score is given to the appropriate criteria. The Random Consistency index (RI) score in this research is 1.32 and applied to all variables in general since we have seven variables.

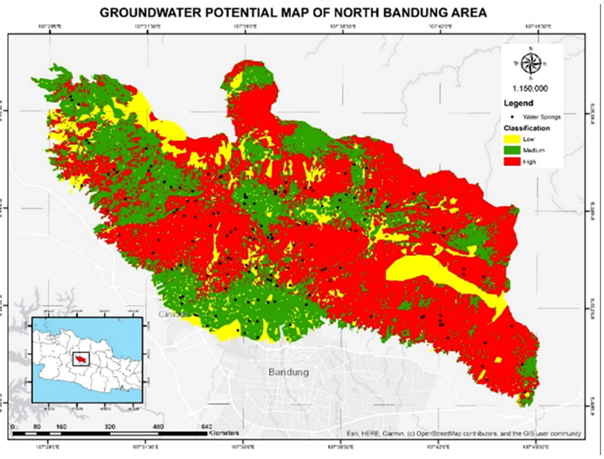

Figure 3. Groundwater Potential Map

Each variable's specific RI value is different based on the number of indicators dependent on the RI table (Table 2).

The analysis of potential groundwater results in five classifications they are low for as wide as (44.13 km^2), medium for (133 km^2), and high for as wide as (210.43 km^2). The potential field maps were validated using the spring location survey in every research area. The result shows 147 springs in the research area, six springs in the low category, 55 in the medium category, and 86 in the high class. The high classification has more springs than the others, so this method can be an alternative in determining the potential groundwater. Commonly, groundwater lies in the valleys, flat areas with small angle slopes (Table 2).

Conclusions

The model of groundwater determination using AHP can be an alternative by looking at variables such as rainfall, hydrogeology, lineament density, slope, Topographic Wetness Index, drainage density, and land use. The classification map of potential groundwater is divided into three areas: low, medium, and high. The existence of groundwater in the high classification has the most significant number. This condition becomes the validation model that the AHP effectively identifies groundwater in the volcano- and structural-shaped areas. The springs are commonly located in high rainfall areas, highly productive aquifers and wide distribution, high lineament density, flat slopes, high TWI value, low-density river, and the type of ground with an easy-to-absorb-water surface. The survey result shows 147 springs, 86 in the high, 55 in the medium, and six in the low areas.

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