Mapping of groundwater potentiality index parameters using remote sensing and GIS techniques in the southern mountain, Yogyakarta Special Region

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Abstract. In the hydrogeological map sheet of the Special Region of Yogyakarta, the Mountain Zone is categorized as an area of scarce groundwater. This research is intended to determine the parameters of groundwater potential in the area of scarce groundwater according to the Groundwater Potentiality Index (GPI) method, including; fractures, lithology, slope, topography, and rainfall. Fracture parameters, distribution, and topography were collected from the Indonesia Geospatial Portal and the Digital Elevation Model (DEM). The lithological parameters were obtained from data from the Geological Agency due to the Interpretation of Remote Sensing Images. Rainfall data for the last ten years was obtained from reports. Results show that most of the research area is a fairly massive rock area, and there are some local faults. The lithological parameters indicate that the research area is composed of breccias, sandstones, and tuffs. Distribution parameters obtained information that most distribution is noted river orders 1, 2, and 3 with several river orders notation 4, 5, and 6. The slope varies from <3% to >65%, and the intensity of rainfall almost evenly ranges from 1600-2100 mm/year.

Keywords: groundwater potentiality index, Yogyakarta special region, the southern mountain

1. Introduction

Based on the hydrogeological sheet map of the Yogyakarta region (Djaeni [1]), the Southern Mountains, the Special Region of Yogyakarta, which includes the districts of Dlingo, Imogiri, Piyungan, and Pleret (Bantul Regency), as well as Patuk, Gedangsari, Nglipar, and Ngawen Subdistricts (Gungungkidul Regency) is a zone of scarce groundwater and drought is often reported every year (Hidayat [2]). Based on the Southern Mountains' lithology, the Special Region of Yogyakarta is dominated by sandstone, breccia, and tuff. These rocks have very low permeability. Furthermore, this research area is included in the non-groundwater basin area.

The study of assessing and determining potential groundwater zoning using field observations is costly and time-consuming. The application of geospatial technology has provided the best alternative for rapid understanding of the presence of groundwater and mapping of groundwater potential in geological studies. Geographic information systems (GIS) are very effective in processing and analyzing large amounts of spatial data and are considered more informative. Furthermore, spatial data collection is carried out using remote sensing devices within a certain time. GIS allows to an analysis of thematic data that can be combined into one required information. For this reason, GIS is used in this study to
determine the groundwater potential zone by using several aspects that affect the presence of groundwater. Researchers with various multi-criteria techniques have widely used the concept of determining potential groundwater zones like this.

Thematic mapping in GPI parameters in this study is a mapping to find potential groundwater zones. In several studies in the world, thematic maps have been widely used to determine potential groundwater zones using remote sensing and GIS interpretation. Researchers have used some or all of the parameters such as geomorphology, geology, soil type, land use/cover, slope, lineament density, lithology, distribution, weathering depth, to rainfall. Dwivedi [3] used four parameters: lithology, slope, lineament, and distribution to determine potential groundwater zones in India. Benjmel [4] used 11 parameters to map groundwater potential in the Ighrem region of Morocco. Atmaja [5] uses five parameters for mapping groundwater potential zones in Banjarnegara, Indonesia. Celik [6] considers eight thematic parameters for mapping groundwater potential in Turkey. Berhanu and Hatiye [7] used geomorphological features, geological factors, lineaments density, and slope as the dominant factors for mapping groundwater in the Megech watershed, Ethiopia. The number of parameters used varies widely from country to country.

This study aims to map the factors supporting groundwater's presence based on the GPI method parameters using remote sensing interpretation and Geographic Information Systems (GIS). These parameters include; fractures and lineaments, lithology, distribution, topography, and rainfall. Furthermore, this study utilizes remote sensing techniques and GIS as integration to evaluate potential groundwater zones based on GPI parameters. Evaluation and analysis of each GPI parameter's values and maps will be a guideline for determining potential groundwater zones using GPI.

Figure 1. Location of the study area
2. Materials and Method

2.1 Study Area

The research area is located in the Southern Mountains, Yogyakarta Special Region, Indonesia. Administratively, the study area consists of 8 sub-districts in 2 districts. The study area is limited to the rare groundwater zone. The research area covers an area of 258.47 km² located at 110° 22' - 110° 44' East Longitude and 7° 46' - 7° 58' South Latitude.

2.2 Methods

The results of this study will be used as the basis for determining the value of the Groundwater Potentiality Index (GPI). Ettazarini [8] uses five parameters to determine GPI: fracturing/lineament, lithology, slope, drainage, and rainfall. This study describes a map of the determinants of the groundwater potential index (GPI) using the notation according to each factor (as shown in Table 1). The use of the GPI method with this multi-criteria model has proven good results in studies in the southeastern boundary of Bouregreg and the Central Moroccan coastal basin, which is dominated by Paleozoic outcrops (Ettazarini [8]).

To evaluate the groundwater potential zone using the GPI method, five parameters: fracture/straightness, lithology, distribution, slope, and rainfall were chosen as influencing factors. The occurrence and presence of groundwater is believed to be influenced and highly dependent on these factors. The description/mapping of these parameters is done based on the notation values in Table 1 below. The notation value is adjusted to the conditions of the research area.

Table 1. Summarized charter adopted for the groundwater potentiality index calculation (Ettazarini, [8])

| Parameters | Description and notation |
|------------|--------------------------|
| Fracturing | 8-10 : interconnected major faults, kilometer long faults, shear zone  
4-7 : local faults, frequent fracture plans interconnected and neared plans  
2-3 : frequent diaclases, crack sand schistosity plans  
1 : non fractured rock |
| Lithology  | 8-10 : porous and fractured sandstone, fractured conglomerate, vacuolar basalts, and dolerites  
7 : alternation of fractured sandstone and micro-conglomerate  
6 : fractured micro-conglomerate, basalt  
5 : fractured sandy schist, fractured sandstone, fractured limestone  
4 : compact sandstone, compact micro-conglomerate, fractured schistose sandstone, pelite and sandstone alternation, alternation of fractured schist and sandstone, fractured siltstone  
2-3 : feebly fractured schist, weathered schist, schist, and quartzite alternation, quartzite  
1 : compact schist, compact granite, compact quartzite |
| Drainage   | 9-10 : permanent waterway of order up to 6;  
8 : waterway order (6); 7 : waterway order (5);  
6 : waterway order (4); 5 : waterway order (3);  
1-4 : uphill area, isolated ravine, temporary waterways, waterway order <3 |
| Topography (slope%) | 10 : slope <3; 9 : slope 3-6; 8 : slope 6-9; 7 : slope 9-12; 6 : slope 12-24; 5 : slope 24-30; 4 : slope 30-45; 3 : slope 45-54; 2 : slope 54-65; 1 : slope >65 |
| Rainfall (mm/year) | 10 : >900; 9 : 800-900; 8 : 700-800;  
6-7 : 500-700; 4-5 : 300-500;  
3 : 200-300; 2 : 100-200; 1 : <100 |
Remote sensing and GIS techniques have become very popular in recent decades to identify potential groundwater recharge zones. Multi-criteria analysis techniques have been used in various studies to describe potential zones for groundwater recharge. Several factors control the absorption capacity of a region, but its dominance varies from region to region. Controlling factors such as geology, geomorphology, slope, and distribution are used in this study because they are considered the most dominant factors in groundwater recharge, especially in this study area.

Methods such as Figure 2 are used to obtain a thematic map according to the GPI criteria.

![Flow chart of methods](image)

Figure 2. Flow chart of methods

Lineaments can represent fracture systems, discontinuity planes, faults, and shear zones in rocks. The straightness can be identified on the satellite image. The alignment and channeling are identified from the Digital Elevation Model (DEM). The DEM of the study area is provided as DEMNAS, which the Indonesian Geospatial Agency publishes. DEMNAS has a spatial resolution of 0.27 arcseconds. The straightness layer is usually converted to a measurable quantity such as density. However, in this study the straightness is conventionally defined and classified according to the classification table 1 to find the value of the GPI parameter notation. The slope is the main factor in the flow of water by the influence of gravity. Slope maps were generated from DEMNAS data using tools in ArcGIS 10.7. Then the slope map is presented in degrees. Lithology affects the permeability of aquifer rocks and the distribution of fracture patterns. The lithological map in this study is based on a 1:50,000 scale geological map. The Indonesian Geological Survey Center published the map. The geological map is generated from remote sensing interpretation using several basic data, including IFSAR, RADARSAT2, TERRASAR X, SRTM 30 m and 90 m; LANDSAT V and ETM +7; ASTER, ALOS (AVNIR), regional geological maps, and topographic maps. Drainage uses the Shuttle Radar Topography Mission (SRTM) and 1:50,000 scale maps to digitize the mainstream channel. Digitally obtained channels are used as river and lake boundaries. Drainage is calculated as the total length of the river and is expressed as km/km². Rainfall data in the study area was obtained by the Department of Public Works, Housing and Energy, and Mineral Resources Yogyakarta Special Region. Rainfall is the main source of groundwater absorption. This determines the amount of water that will seep into the groundwater system.

3. Results and Discussion

3.1. Fracturing/Lineament

Lineament is a structurally formed fracture in rock with a linear or curved appearance. The lineament in the massive rock area is very important to determine the groundwater potential because the lineament
increases the permeability and porosity. A high lineament density creates good groundwater potential because the infiltration rate is higher, whereas a low lineament density results in low water infiltration. Based on the lineament fracture parameters, major fault types were found in shear fault structures in the southwest, northeast, and center of the study area. Major faults gave the notation 8-10 are located in the Dlingo, Imogiri, and Ngawen areas. Notation 4-7 in the form of local faults located in the Patuk, Gedangsari, Nglipar areas and a fault extending from Piyungan to Pleret. Furthermore, most joints/fractures or massive rocks are found in each area as shown in Figure 3.

3.2. Lithology
Lithology in the landscape affects the availability of groundwater. Alluvial areas show good groundwater potential, while lithology with a high elevation and steep slopes indicates low groundwater potential. There are six lithological groups in the research area: Alluvium, Sambipitu formation, Nglanggran formation, Semilir formation, Kebo formation, and Butak formation. Parameter notation in
this area is classified in the notation between 2 – 7. The lithology parameter mapping is as shown in Figure 4.

3.3. Drainage
Areas with very high distribution density indicate proximity to the river channel. An area has good groundwater potential if the density of river flow distribution is high so that the runoff will be greater. However, a generally moderate to high dispensing density implies a low or moderate potential for infiltration and recharge (Figure 5).

3.4. Slope
Land slope or degree of surface steepness is a vital terrain characteristic to control soil infiltration. The slope of the land strongly influences infiltration and runoff capacity. Steep slopes increase runoff and decrease infiltration rates. Areas with steep slopes indicate that the area has good groundwater potential. The ArcGIS spatial analysis tool developed district slope maps from the DEM (Figure 6).

The slope of the research area is classified into ten classes. Groundwater potential occurs on sloping slopes to lowlands because the water flow is slow, and the time available is sufficient to increase water infiltration into the fractured aquifer below. Therefore, the lower degree of slope is given a higher notation than the higher degree of slope. The slope of 0 is given the highest notation, 10. While the slope of more than 65 is given the lowest notation, 1 (Figure 6).

3.5. Rainfall
Rainfall data in the study area were obtained from data from 2011 to 2019. The highest rainfall was in the Patuk, Gedangsari, and Nglipar areas, ranging from 2000 – 2250 mm/year. Then, it can be seen in Figure 7.

The distribution of rainfall in the study area ranges from 1.250 to 2.250 mm indicating a humid tropics with the entire study area receiving more than 1.000 mm of rainfall annually (Figure 7). Areas with high rainfall have factors that indicate good groundwater potential.

4. Conclusions
The application of remote sensing and GIS technology in research is an effective, time-saving, cost-effective, and energy-saving technique because it does not have to conduct field surveys. Furthermore, remote sensing and GIS techniques provide the data needed to identify and map GPI parameters. However, besides that, remote sensing and GIS techniques have drawbacks. Remote sensing and GIS techniques provide images that are temporal and sometimes get images that are not up to date. Data with high resolution and current conditions will produce better data results to determine the map for determining groundwater potential.
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