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Groundwater Potential Zone Classification Using Geospatial Approach

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ABSTRACT

Groundwater is an important process in the watershed hydrological system. Serayu watershed, the largest in Central Java Province, has bio-physic spatial variability that influences groundwater recharging. The aim is to derive the groundwater potential zone of the Serayu watershed. Five thematic maps used and applied for groundwater potential analysis, were lithology, land use land cover, lineament density, drainage density, and slope gradient. Distribution of Lithology data, Digital Elevation Model (DEM), and Landsat 8 image were analyzed to thematic raster with 1 x 1 km resolution. Weighted index was calculated regarding the relation of five influence parameters then were overlaid and calculated by using QGIS-calculator. Groundwater classified into five categories, namely poor, low, moderate, good, and very good. Based on the final groundwater potential map, 0.02% of 3,727 km^2 is poor category, however most of Serayu watershed have moderate to good (48.77 and 29.77 %, respectively). The percentage of very good (10.57%) and low (10.87%) classes were rather similar. Spatial variability of groundwater distribution indicates the complex characteristics of the Serayu watershed, so more serious attention from the perspective of research and management of water resources in the future, is needed.

1. INTRODUCTION

Groundwater is an important process in the watershed hydrological system. Spatial-temporal variability influence groundwater especially water recharge and groundwater storage. Some studies reported drawbacks to groundwater due to land use degradation and climate change (Goderniaux *et al*., 2011; Liaqat *et al*., 2021). Whereas, groundwater is a primary factor in water balance as contributes around one-third of the annual water source and imperative for domestic freshwater resources (Yeh *et al*., 2009). In addition, freshwater resources contribute only 3% of total water in the earth and one-third are present as groundwater (Shiklomanov, 1998). Thus, water resources sustainability should be a crucial concern across the hydrological region such as watershed.

Serayu watershed condition, the largest watershed in Central Java, was reported as a critical watershed due to water and soil erosion problems (Purnama, 2018). Studies on groundwater potential are rarely carried out in hydrological systems, and some studies focus on surface biophysics such as flow discharge, soil erosion, and land cover vegetation (Christanto *et al*., 2018; Marhendi, 2018; Ngadisih *et al*., 2018). Two studies on groundwater in the Serayu watershed were carried out using spatial and geoelectrical analysis (Atmaja *et al*., 2019; Herho *et al*., 2018), but these two studies had a small study coverage, namely the sub-watershed level. Based on the study, it was reported that the eastern Serayu watershed has low to moderate groundwater potential and vice versa with the western watershed.

The geospatial approach to mapping the potential of groundwater in a watershed area is more developed than the conventional method. Conventional methods are carried out by direct measurement, including the borehole method, pumping test, tracer test, and bail test (Díaz-Alcaide *et al*., 2017; Freeze & Cherry, 1979; Nsiah *et al*., 2018). Direct measurements can also be carried out with advanced technology such as electrical resistivity tomography (ERT) (Alshehri & Abdelrahman, 2021). The direct field exploration approach requires a long time and is expensive, in contrast to the geospatial approach. Several studies use different parameters for mapping groundwater potential using a geospatial approach. Huang *et al*. (2013) used five parameters, namely lithology, land use/land change (LULC), lineament density, drainage density, and land slope, while Yifru *et al*. (2020) uses twelve parameters as complex interaction parameters. They state lithology is the most influential parameter on groundwater because it involves permeability and water storage capacity.

Studies on the potential for groundwater recharging in a watershed hydrological system using a geospatial approach have not been widely carried out, especially in the Serayu watershed. Therefore, this study aims to obtain groundwater potential zones in the Serayu watershed. Based on previous studies, five parameters (ie lithology, LULC, lineament density, drainage density, and land slope) were analyzed using spatial analysis to map groundwater potential zones.

2. MATERIALS AND METHODS

2.1. Location

The research was conducted in the Serayu Watershed, which is located in the southwest of Central Java Province, Indonesia. Serayu Watershed has an area of 3,727 km^2 and is located between latitude 7010'03"-7044'20" S and longitude 108056'45"-11004'24" E. The topographical pattern shows hills in the north and sloping plains in the south (Figure 1). The Serayu watershed consists of nine sub-watersheds: Begaluh, upstream Serayu, Tulis, Merawu, Klawing, Sapi, Logawa, Tajum, and downstream Serayu. Serayu River is the main river with a length of 305.81 km. The research location is included in a tropical monsoon climate with an average annual rainfall of 3.577 mm/ y. Maximum river discharge occurs from January to March (approximately 60 m^3/s) and minimum discharge occurs from August to September (approximately 11 m^3/s).

2.2. Materials

The classification of groundwater potential zones was begun with the preparation of five thematic maps at the study site, namely lithology, land use land cover, lineament density, drainage density, and land slope. Data on the distribution of lithology was obtained from the Ministry of Energy and Mineral Resources of the Republic of Indonesia (https://geoportal.esdm.go.id/geologi/). Landsat 8 OLI/TIRS C2 L2 image (i.e.

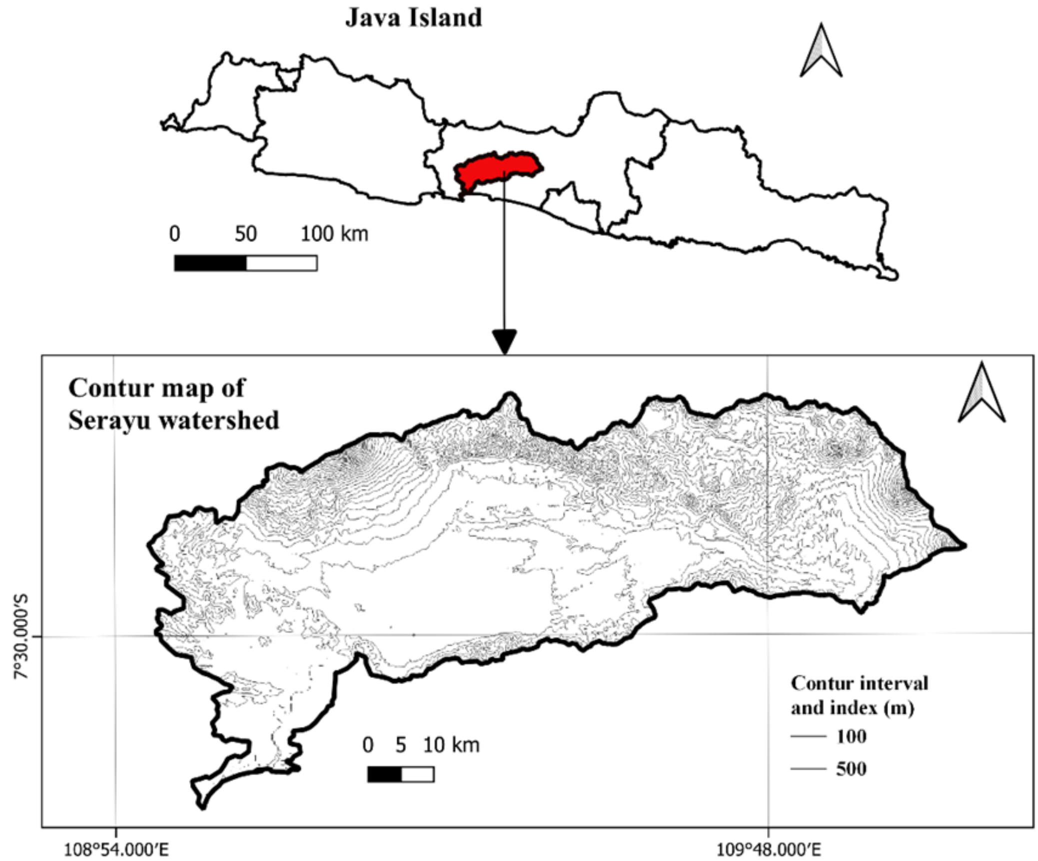

Figure 1. Study site of Serayu watershed represented by topographic map with contour interval 100 m.

path 120-121, row 065) was collected from the United States Geological Survey (USGS: https://earthexplorer.usgs.gov/). The minimum distance algorithm used for LULC analysis followed the procedure of Hardanto *et al*. (2021). Lineament density, drainage density, and land slope were analyzed using DEM (*Digital Elevation Model*) data downloaded from the Geospatial Information Agency (https://tanahair.indonesia.go.id/). The lineament layers were carried out using the procedure from Iqbal & Juliarka (2019), drainage densities followed the procedure of Çelik (2019), and land slope were processed with the slope tool in QGIS software. Each thematic map has a resolution of 1 km × 1 km. The weighted index represents the modified value of interaction between parameters from Huang *et al*. (2013) and Yeh *et al*. (2009) based on the characteristics of the Serayu watershed. QGIS version 3.18.3 (https://www.qgis.org) was used for geospatial data analysis.

2.3. Analysis

The five most dominant parameters affecting groundwater potential included lithology, LULC, lineament, drainage, and slope (Huang *et al*., 2013; Yeh *et al*., 2009). Appropriate weighting was applied to calculate the geospatial of each parameter based on the relative interaction between parameters. Modified weight categories were used based on watershed characteristics, such as lithology which were defined for different rock types but are similar in the number of divisors. The calculation of the proposed score for the influence parameter and the proposed weighting for each category followed the procedure of Yeh *et al*. (2009) where lithology provides the highest contribution (29) followed by LULC (24), lineament (19), drainage (14), and land slope (14). The value of each parameter was then divided by the same interval as the number of categories and was sorted based on the potential of groundwater that has an effect, from low to high (Table 1). Therefore, the reclassification was carried out on five thematic layers regarding the weight value of each category. Raster analysis using the raster calculator in QGIS to obtain a groundwater potential map (Figure 2).

Table 1. Proposed weight of influencing criteria for geospatial multi-criteria approach (modified from Yeh *et al*., 2009)

Parameter	Criteria	Weight influence
Lithology	Compact sediment	7
	Limestone and dolomite	15
	Tuff and Breccia	22
	Loose sediment	29
Land use/land change	Settlement	6
	Forest and plantation	12
	Agricultural land	18
	Water bodies	24
Lineament density	<2837	4
	2837-5669	9
	5669-8501	14
	>8501	19
Drainage density	<0.0012	4
	0.0012-0.0023	7
	0.0023-0.0034	11
	>0.0034	14
Land slope	$>55^{o}$	4
	$35\text{-}55^{o}$	7
	$15\text{-}35^{o}$	11
	$<15^{o}$	14

3. RESULTS AND DISCUSSION

Thematic raster data set with 1 km x 1 km resolution for each parameter (i.e. lithology, LULC, lineaments, drainage, and slope gradient) affect the groundwater recharging. Each raster pixel represents the value of groundwater potential related to the respected parameters.

3.1. Lithology Impact

Surface rocks influence groundwater storage as dissolved minerals (Naseem *et al*., 2010; Thivya *et al*., 2013), and rock formations control rainwater infiltration and deep percolation (Achu *et al*., 2020; Grinevskii & Pozdnyakov, 2010; Letz *et al*., 2021). The Serayu Watershed is evenly dominated by compacted and loose sediments. Alluvial rocks such as breccias and tuff are found in the highlands of Slamet, Sindoro, and Mount Sumbing, while limestone and dolomite are present in the southwestern part of the Serayu watershed (Figure 3). Soil texture and structure relate to infiltration and percolation which contribute to groundwater recharging. Previous studies have shown relatively higher percolation in sand-dominated units than clay units (Andersen, 2020). In addition, compacted sediment, which limits the pores, affects infiltration ability.

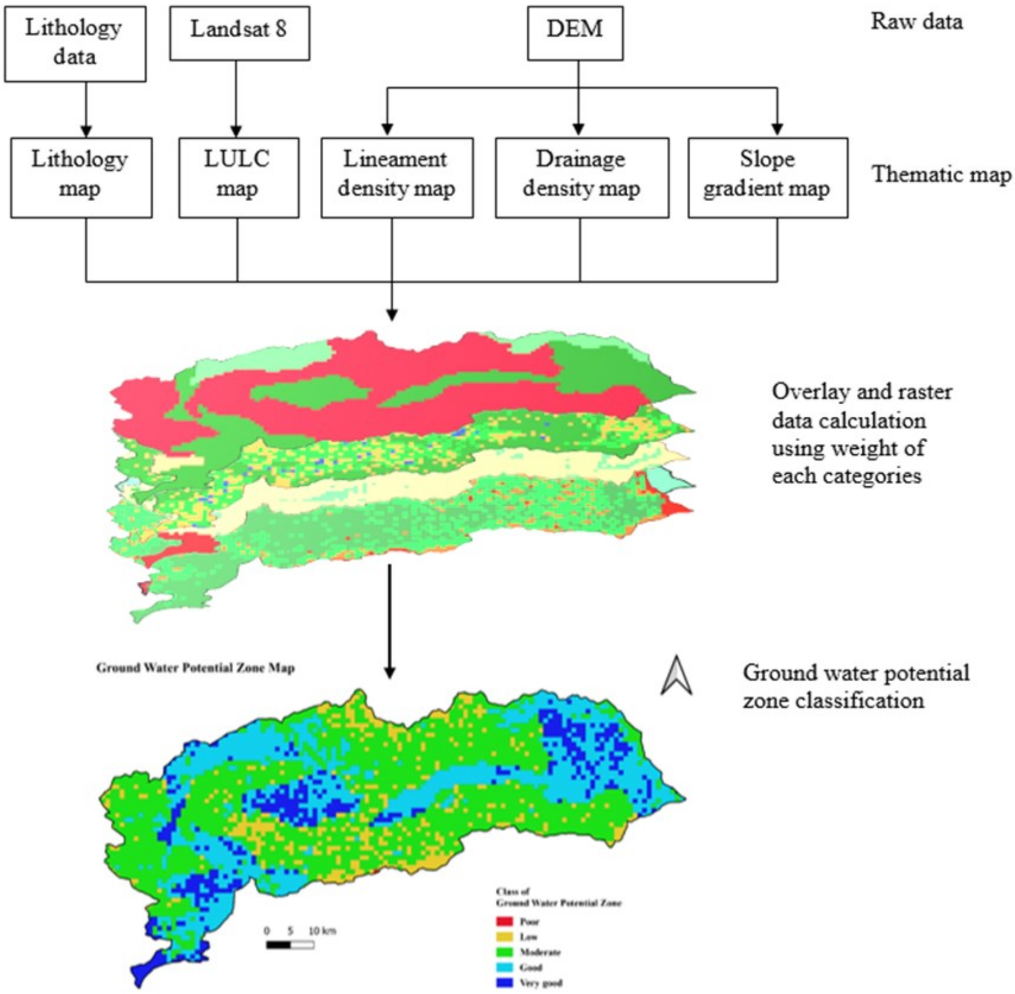

Figure 2. Multi-criteria geospatial approach procedure

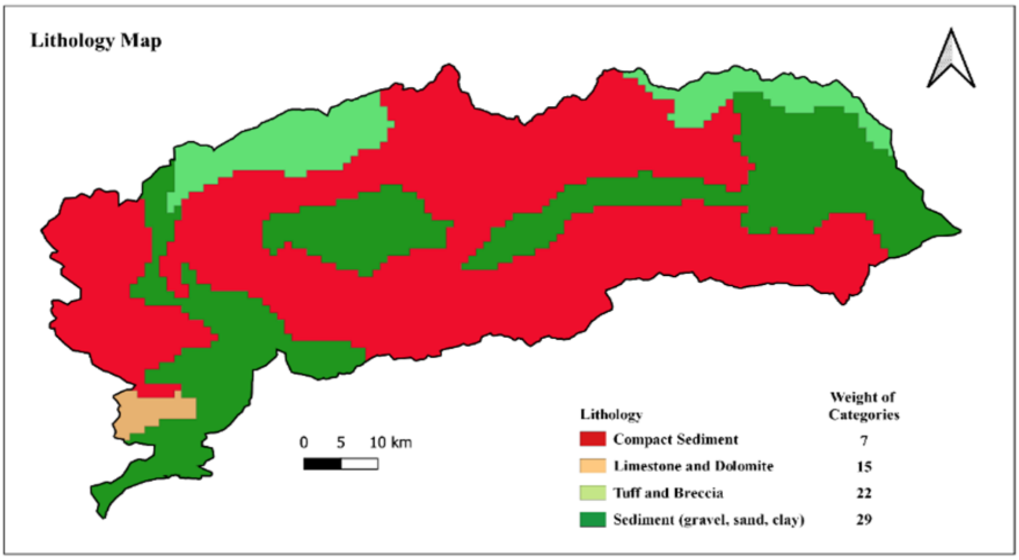

Figure 3. Lithology distribution map of Serayu watershed and weight value

Lithology is a parameter controlling groundwater potential because it influences the characteristics of aquifer materials such as porosity and permeability (Ayazi *et al.*, 2010; Kabeto *et al.*, 2022). The groundwater potential obtained is slightly different between solid and loose sediments in the Serayu watershed, but both are in the moderate to good category. Based on these results, the lithology may be quite influential according to the contribution of groundwater recharging. The lithology of the Serayu watershed is relatively the same because it was formed from volcanic material, in the form of limestone and dolomite, with an area of more than 50 km^2.

3.2. Land Use/Land Cover

LULC affects water absorption significantly and is grouped into five types such as settlements, forests, plantations, agricultural land, and bodies of water. Galata *et al.* (2020) stated that an increase in residential area was followed by a decrease in groundwater percolation due to the compacted soil structure and closed soil pores for infiltration processes, while vegetation has a positive correlation with water absorption ability. The Serayu watershed is dominated by forests and plantations (including gardens). The Serayu watershed is detected very small due to the wide raster map resolution. Carroll *et al.* (2009) found more detailed bodies of water when using a high raster resolution of 250 m x 250 m.

Residential areas and agricultural land are located in lowland areas and close to riparian zones (Figure 4) due to soil conditions, convenient access and facilities, water resources, and microclimate (Hermawan & Švajlenka, 2022; Herrmann & Hammer, 2019; Laermanns *et al.*, 2019; Morton & Olson, 2018). Increased exploitation of groundwater in any region is followed by a pattern of lowering the groundwater table (Li *et al.*, 2021). Thus, the settlement has many potential shortages of groundwater due to increased runoff when it rains. In contrast, vegetated land cover (e.g. agricultural land and forest) contributes positively to groundwater potential due to higher infiltration (Kabeto *et al.*, 2022; Li *et al.*, 2018; Singh *et al.*, 2010).

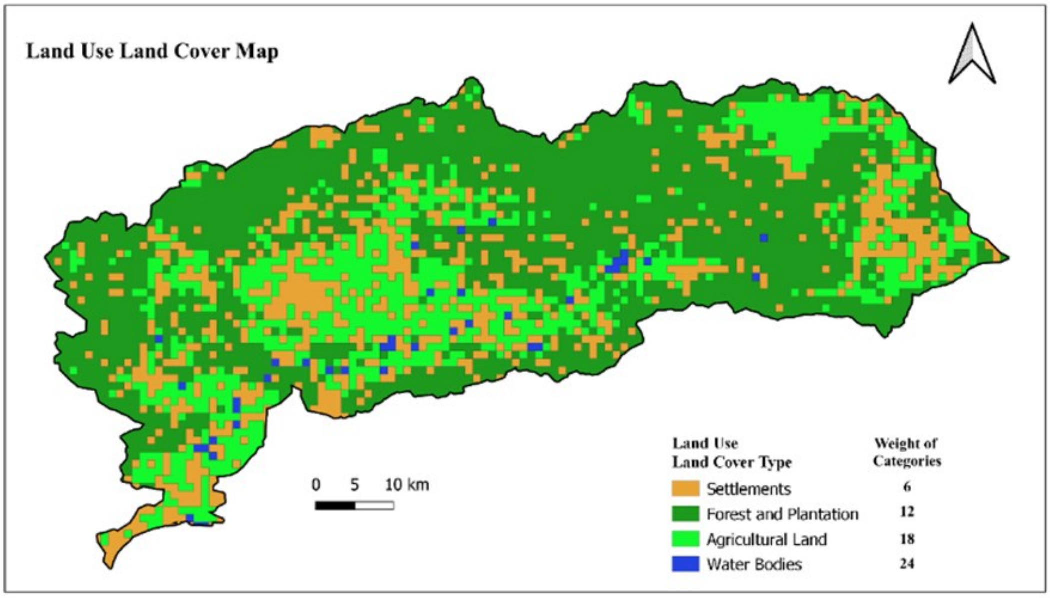

Figure 4. Land use and land change (LULC) of Serayu watershed and weight value

3.3. Lineament Density

The lineament density indicates the total lineament length per unit area (km/km^2) and represents the fracture zone, which increases porosity and permeability. The results of the analysis show that in the upstream part of the Serayu watershed the lineament density is higher than in the middle and downstream parts (Figure 5). The undulating topographic pattern may be related to lineament distances such as in the upper Serayu watershed (Hardanto *et al*., 2021). The lineament also reveals an indicator of increasing groundwater potential with decreasing lineament distance and vice versa, because lineament provides a path for water movement (Nasir *et al*., 2018; Arulbalaji *et al*., 2019; Kumar, 1999).

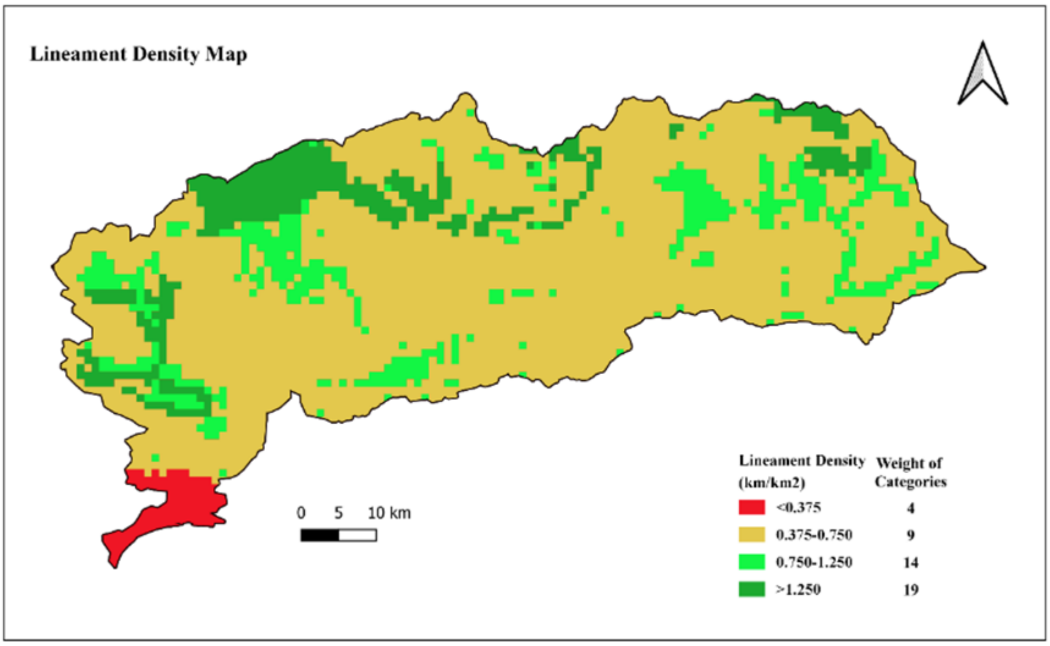

Figure 5. Lineament density map of Serayu watershed and weight value

3.4. Drainage Density

The drainage density is obtained from the total flow length of all flow sequences per unit area (Magesh *et al*., 2012). Drainage density involves surface slope and lithology. This function is inversely proportional to the level of infiltration and permeability. A high drainage density indicates less infiltration, so it has less groundwater potential (Ghosh, 2021). The results of the analysis show that the drainage density is slightly spread over the Serayu watershed, especially in the middle and upper reaches of the river (Figure 6). Less drainage density in the southwestern part of the Serayu watershed indicates “good” to “very good” groundwater potential. Similar results are also presented in small basins that very good water catchment zones are shown in downstream basins due to low drainage density (Yeh *et al*., 2009).

3.5. Land Slope

Groundwater recharging in tropical areas such as the Serayu Watershed is mainly obtained from rainfall. There is a direct effect between the slope of the land and the infiltration rate. The steep slope of the Serayu watershed is shown at the basin boundary, especially in the northern to eastern and decreases towards the Serayu river

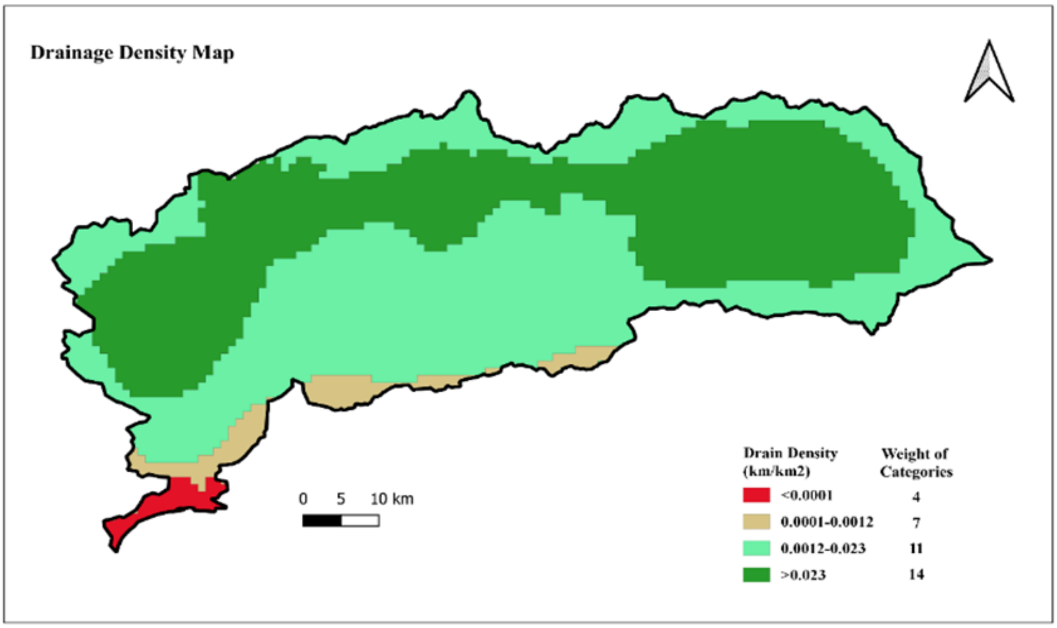

Figure 6. Drainage density map of Serayu watershed and weight value

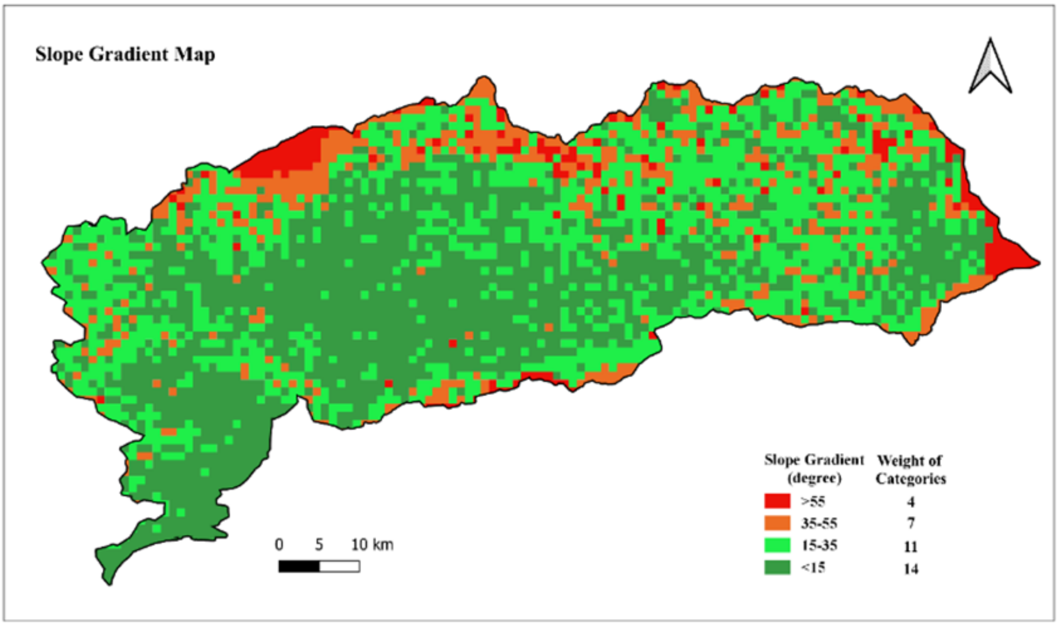

Figure 7. Slope gradient map of Serayu watershed and weight value

(Figure 7). Areas with higher slopes produce less water recharging than sites with less slopes, due to the rapid runoff velocity. Thus, areas with a lower slope have a higher ability to collect rainwater and turn it into a water recharge process (Chaudhary & Kumar, 2018).

3.6. Land Slope

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3.7. Groundwater Potential Zone (GWPZ)

The geospatial approach that analyzes five parameters that affect the groundwater potential zone is then categorized into five classes, namely bad, low, medium, good, and very good. Groundwater potential in the Serayu watershed is presented in Table 2. The moderate to very good zones are located in the middle to the downstream watershed according to the direction of water movement. Several relevant studies were also presented on mainland and Middle East Asia (Mallick et al., 2019; Saranya & Saravanan, 2020).

Table 2. Groundwater potential classification area of Serayu watershed

Class interval	GWPZ Classification	Area	
		(ha)	(%)
<33	Poor	63.01	0.02
33-48	Low	40,501.14	10.87
48-63	Moderate	181,792.01	48.77
63-79	Good	110,978.26	29.77
>79	Very good	39,406.57	10.57
Total		372,740.98	100.00

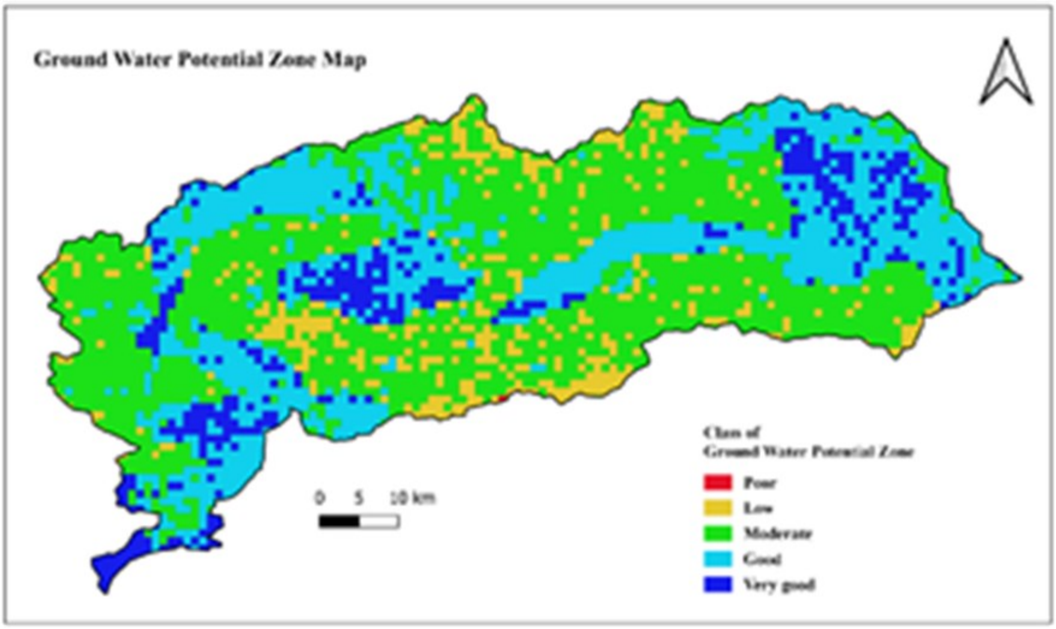

Figure 8. Groundwater potential classification zone of Serayu watershed

Based on spatial analysis, groundwater potential values that are categorized as "good" and "very good" are in the lowland areas. This is probably caused by the lithological conditions of the rocks in the area which are dominated by sedimentary rocks (Figure 8). Jung (2020) states that sedimentary rocks have good water absorption values due to their conductivity and hydraulic permeability even though they contain little organic matter. Several studies have also assigned the highest lithological parameter values for groundwater potential analysis (Chaudhary & Kumar, 2018; Huang *et al*., 2013; Magesh *et al*., 2012; Yeh *et al*., 2009).

Chaudhary & Kumar (2018) added two additional spatial data (namely rainfall and soil type) and found an increase in accuracy of more than 80%. Comprehensive results also present an analysis of groundwater potential using 12 parameters that was carried out in the Katar watershed in Africa (Yifru *et al*., 2020). In addition, the complexity of the watershed parameters that affect groundwater potential needs to be considered in the spatial analysis. Related to the advanced analytical approach, several studies provide convincing results regarding data quality and analytical methods. For example, bodies of water are clearly detected, when high-resolution images are analyzed (Carroll *et al*., 2009). Artificial intelligence such as analytical hierarchy process (AHP) based on fuzzy algorithms is a more appropriate approach than conventional AHP and weighted criteria (Huang *et al*., 2013; Sresto *et al*., 2021; Yeh *et al*., 2009b; Yifru *et al*., 2020).

The final spatial multi-criteria analysis map presents the heterogeneity distribution of groundwater potential zones in the Serayu watershed. This suggests that the lack of results of this study should be considered for future studies, namely to include more parameters and methods of spatial analysis. Nonetheless, mapping the potential of groundwater supports and can be used to assist the management of water resources and government in local and global contexts, especially in water crisis conditions which are influenced by space and time variables (Kendarto *et al*., 2021; Zipper *et al*., 2020).

4. CONCLUSIONS

Five thematic maps were analyzed using QGIS, including lithology, LULC, lineament density, drainage density, and land slope. Potential groundwater is scattered sporadically along the Serayu Watershed, but appears to be abundant in moderate to good conditions. The distribution of groundwater potential zones is classified as bad at 0.02% or an area of 0.63 km^2, is classified as low as much as 10.87% or an area of 405.01 km^2, is classified as medium as much as 48.77% or an area of 1817.9 km^2, and is classified as good as much as 29.77% or an area of 1109.8 km^2, and classified as very good as much as 10.57% or an area of 394.1 km^2. The spatial variability of the groundwater potential zone shows the complexity of the characteristics of the Serayu watershed, so that further approaches need to be considered in the management of water resources and future research perspectives.

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