Delineation of Groundwater Potential Zones Using Remote Sensing, GIS, and AHP Techniques in the Southern Region of Banjarnegara, Central Java, Indonesia

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ABSTRACT

Southern region of Banjarnegara Regency, Central Java, Indonesia have been experiencing water scarcity throughout dry season every year due to meteorological and geological condition. Meteorological drought in dry season have been recorded since 1984. About 85,000 people are affected. Local authorities were forced to send clean water aid routinely. This study aim to delineate groundwater potential zones using remote sensing, Geographical Information System (GIS), and Analytic Hierarchy Process (AHP). This study evaluate groundwater potential zones using 5 factors involving lineament, lithology, slope, drainage, and rainfall. Digital Elevation Model (DEM) from DEMNAS (published by Indonesian Geospatial Agency) was used to generate lineament delineation and slope map. Hydrography data provided by Indonesian Geospatial Agency was used to generate drainage density. Geological maps which were generated from remote sensing interpretation were provided from Geological Survey Center of Indonesia. Rainfall data were provided by BPS-Statistics of Banjarnegara. 52 springs and 2 bore wells data were used for result validation. All 5 thematic layers were prepared in GIS. All factors and its classes were assigned weights using AHP techniques and normalization of weights was conducted through the AHP. Groundwater potential zones map were generated, the results was classified into five zones as very high, high, moderate, low, and very low. The zones covered of 1.02 km^2 (1.18%), 14.49 km^2 (16.80%), 33.65 km^2 (38.99%), 37.12 km^2 (43.02%), and 1529 m^2 (0.00%) of study area respectively. Result validation by comparing the AHP map values with discharge of springs and bore wells showed promising result.

Keywords: groundwater potential zones, AHP, GIS, remote sensing, Banjarnegara, Indonesia

1. INTRODUCTION

Banjarnegara is located in the central part of Central Java, Indonesia. According to various reports, southern area of Banjarnegara encountered drought and clean water scarcity throughout the dry season in 2017 [1 2 3 4 5 6]. Local authorities had to send clean water aid to the community routinely. Drought happened not only in 2017, southern region of Banjarnegara have been experiencing meteorological drought since 1984. The peak of dry to very dry condition occur on August until November every year [7].

Based on hydrogeological condition, southern region of Banjarnegara is a region without exploitable groundwater [8]. It correspond with its geological condition which mainly consist of igneous rocks, metamorphic rocks, and mélange [9 10]. Those rocks assemblages have low permeability [8]. Furthermore, southern region of Banjarnegara is considered as non groundwater basin area [11]. Therefore, various factors are responsible for drought and clean water scarcity in southern region of Banjarnegara including rainfall, geological condition, and unfavorable topographic condition.

About 85,000 people live in 18 villages in southern region of Banjarnegara [12 13 14 15]. They have been encountering drought and clean water scarcity in dry season every year. Those huge amount of affected people encourage to execute a mitigation effort and propose solutions. This study aim to delineate groundwater potential zones in the hard rock terrain of southern region of Banjarnegera, Indonesia using remote sensing, Geographical Information System (GIS), and Analytic Hierarchy Process (AHP). The map can be used as prospective guide for groundwater exploration and exploitation to fulfill community's need for clean water.

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Sixth Geoinformation Science Symposium, edited by Sandy Budi Wibowo, Andi B. Rimba
Stuart Phinn, Ammar A. Aziz, Proc. of SPIE, Vol. 11311, 113110O · © 2019 SPIE
CCC code: 0277-786X/19/$21 · doi: 10.1117/12.2548473

Application of remote sensing which is combined with GIS can increase the accuracy of result in delineation of groundwater potential zone and also to reduce bias on any single theme [16].

Integration of RS and GIS is an effective tools in terms of cost and time for assessing and managing groundwater resources [17, 18, 19, 20, 21, 22, 23]. Numerous research all over the world conducted GIS techniques in order to identify groundwater potential zones [20, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33].

In recent years, the evaluation of groundwater potential zones is conducted using Multi Criteria Decision Analysis (MCDA). One of the most effective and most used MCDA method is AHP method. AHP provide mathematical objectivity to process subjective preference which is inevitable from individual or group in decision making. In principal, AHP works by developing priorities for alternatives and criteria which is used to evaluate alternatives [34, 35]. Integration of GIS and AHP method have been successfully applied to delineate groundwater potential zones by numerous research [36, 37, 38, 39] with promising results. Furthermore, this research considered lineament, slope, rainfall, lithology, and drainage as influential factors of groundwater resources in hard rock geology condition. However, the weights and the employed thematic data were adjusted based on the investigated study area.

Finally, this study utilized RS, GIS, and AHP techniques as an integration to evaluate groundwater potential zones in southern region of Banjarnegara, Central Java, Indonesia. Evaluation and recognition of groundwater potential could guide the decision makers in groundwater exploration and exploitation to fulfill community’s need for clean water.

2. STUDY AREA

The study area is located in the southern region of Banjarnegara regency, Central Java, Indonesia. Administratively, the study area consist of 18 villages which is distributed in 4 sub-districts. The study area is limited on hydrogeological unit of region without exploitable groundwater [8]. The study area covered an area of 115.89 km^2. It is located between 109^0 30’ and 109^0 45’ East Longitude and 7^0 26’ and 7^0 31.5’ South Latitude (Figure 1). Therefore the climate of study area is tropical. Average annual rainfall from 2010 to 2017 is 4436 mm/year. Humidity is ranging from 71.3% to 91.3%. While annual temperature is ranging from 20.8 ^{0}C to 27.2 ^{0}C.

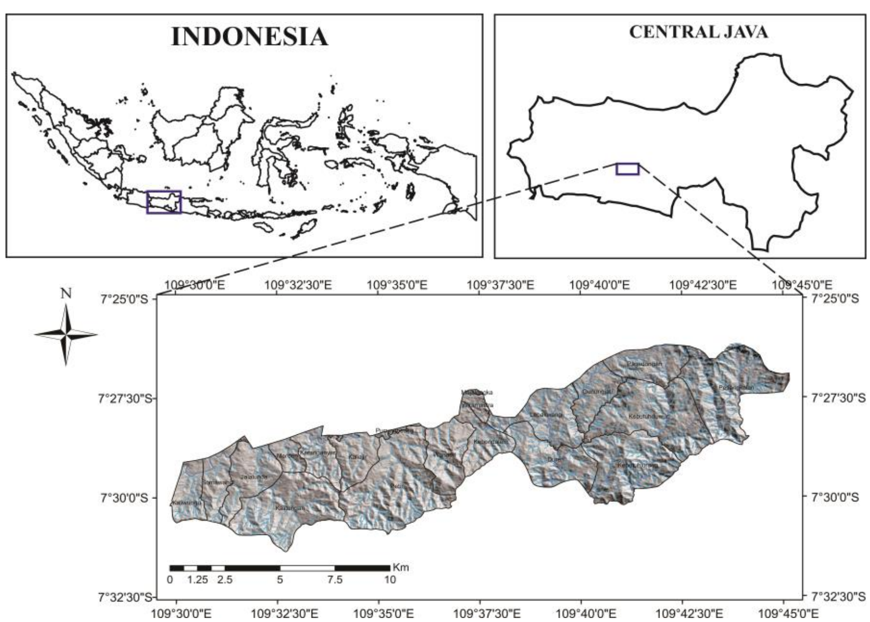

Figure 1. Location of the study area

The study area belongs to physiographical zone of South Serayu Mountains [40]. Geological maps in the scale of 1:50,000 informs that study area consist of 5 tectonites, 4 rock formations, and 2 quaternary deposits [41, 42]. The tectonites including Mélange Luk Ulo Complex, Serpentinite, Mafic and Ultramafic, Brecciated Rocks, and Greywacke. The rock formations comprise of Claystone Totogan Formation, Tuff Waturanda Formation, Sandstone Waturanda Formation. Then, quaternary deposit comprise of Sand Terrace Deposits and Alluvium [41 42]. Furthermore, there are three main geological structure patterns in the study area including northeast-southwest (NE-SW), northwest-southeast (NW-SE), and east northeast-west southwest (ENE-WSW) [43 44 45].

3. METHODS

3.1 Factors influencing groundwater potential

To evaluate groundwater potential zones, five parameters: lineament, slope, rainfall, slope, and drainage were selected as the influential factors. Groundwater resource and occurrence is believed to be influenced and largely depended on those factors. The comprehensive research methods of the groundwater potential evaluation is shown in Figure 2.

Lineaments occur as straight, curvilinear, parallel or en-echelon features. Lineaments may represent fracture systems, discontinuity planes, faults, and shear zone in rocks. Lineaments can be identified on satellite images [46]. Lineaments were identified from Digital Elevation Model (DEM). DEM of study area were provided as DEMNAS published by Indonesian Geospatial Agency. DEMNAS has spatial resolution of 0.27 arc second. Lineaments layer usually is converted into measurable quantity such as density [36 37 38 39]. However, in this study lineaments were conventionally assigned and classified following their capacity to promote groundwater occurrence. This approach was performed in Groundwater Potentiality Index [47]. This approach for lineaments is suitable for hard rock geology condition where groundwater occurrence is mainly governed by fractures.

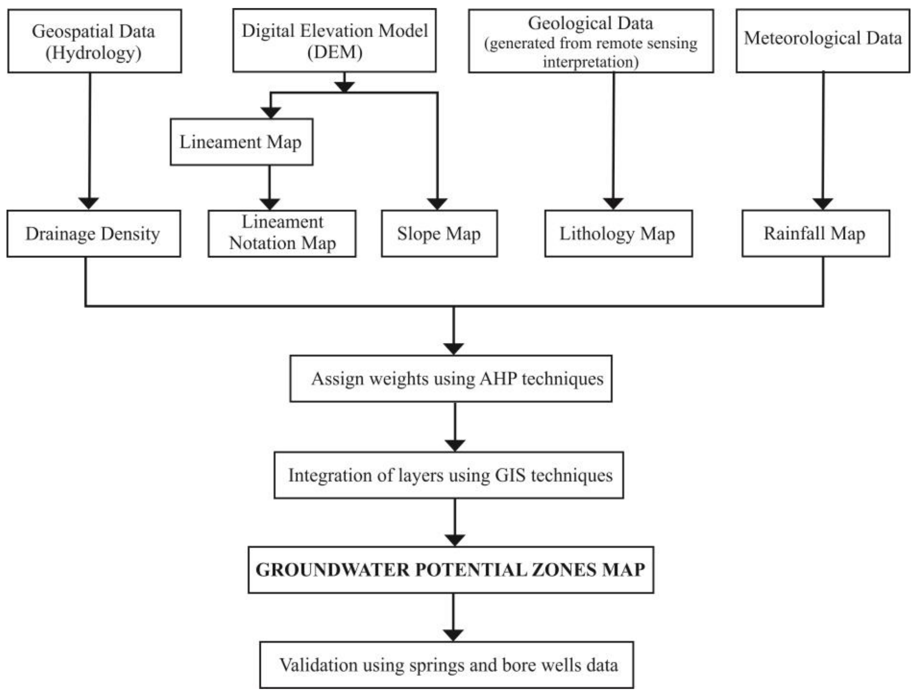

Figure 2. Flow chart of the methods for estimate the groundwater potential of the study area

Slope is principal factor of the superficial water flow since it govern the effect of gravity on the water movement [47]. Slope map was generated from DEMNAS data using tools in ArcGIS 10.4. Then, slope map was presented in degree units. Rainfall data in study area was provided by BPS-Statistics of Banjarnegara. Rainfall is the main source of groundwater recharge [29 48]. It determines the amount of water which would percolate into the groundwater system [50].

The lithology influences both the permeability of the aquifer rocks and the distribution of the fracture pattern [47]. Lithology map in this study was based on geological map in the scale of 1:50,000. The maps were published by Geological Survey Center of Indonesia. Those geological map were 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 geology map and topographic map.

Basic data of drainage was available as hydrography layer which was provided by Indonesian Geospatial Agency. Drainage was processed as density. The drainage density is the ratio of the sum of the lengths of streams to the area of the grid [29 49 50]. Drainage density was calculated using grid size of 8.5 km^2 through the equation 1. This analysis was performed based on analysis which was conducted by Mohammadi-Behzad (2018) [39]. Where, $\sum D_i$ is the total length of all streams i (km) and A is the area of the grid (km^2) [39]. The values obtained for each grid were plotted at the center of the grid, then drainage density map is produced for the area by kriging interpolation technique [39].

$$Dd = \sum_{i=1}^{i=n} \frac{D_i}{A} \ (km^{-1}) \tag{1}$$

3.2 Analytic Hierarchy Process

First step of AHP method is to assign the level of importance of each factors based on Saaty's scale values. Consequently, all factors are compared in a pairwise comparison matrix. The weight which was assigned to different thematic layers were normalized using Saaty's AHP techniques. To control and test the consistency and judgement of the assigned weights, Consistency Ratio (CR) is calculated. First step to calculate CR is to compute maximum eigenvalue (λ_{max}). Then, calculate the Consistency Index (CI) using equation 2, where n is number of factors. CR is resulted by dividing CI by RI (Ratio Index). The value of RI is given based on Saaty's 1-9 scale. If the value of CR is less than 0.1, the judgement of weights is acceptable and consistent.

$$CI = \frac{\lambda\max - n}{n - 1} \tag{2}$$

$$CR = \frac{CI}{RI} \tag{3}$$

3.3 Overlay Analysis

All five thematic layer maps were integrated using ArcGIS 10.4 as a summation of overall groundwater influencing factors to produce the groundwater potential map (GPM) of study area. The following formula was used to estimate the groundwater potential map [18 51 52].

$$GPM = (MC1w \times SC1r) + (MC2w \times SC2r) + (MC3w \times SC3r) + (MC4w \times SC4r) + (MC5w \times SC5r) \tag{4}$$

where GPM is groundwater potential map, MC1–MC5 is the main criteria (1–5 thematic layer map), w is the weight of the thematic map, SC1–SC5 is the sub-criteria of each thematic layer map and r is the sub-criteria class ranking.

4. RESULTS AND DISCUSSION

4.1 Weights and Classes of Layers

The weights for each factors were decided based on the local field experience and expert opinions. The comparison of importance level of all five thematic layers are shown in a pairwise comparison matrix (Table 1). Normalized weight is presented in Table 2. Based on calculation, Consistency Ratio (CR) of this research is 0.0095 which mean that the judgement of the pairwise comparison matrix is consistent. Hence, the assigned weight for lineament, slope, rainfall, lithology, and drainage are 0.3892, 0.2141, 0.1987, 0.1213, and 0.0767 respectively. Ranks was assigned to different class of the individual themes are presented in Table 3. The thematic maps for all layers are presented in Figure 3.

Table 1. Pairwise comparison matrix for AHP processing

Factors	Lineament	Slope	Rainfall	Lithology	Drainage
Lineament	1	2	2	3	5
Slope	1/2	1	1	2	3
Rainfall	1/2	1	1	2	2
Lithology	1/3	1/2	1/2	1	2
Drainage	1/5	1/3	1/2	1/2	1
Column Total	2.53	4.83	5	8.50	13

Table 2. Normalized weights for thematic layers

Factors	Lineament	Slope	Rainfall	Lithology	Drainage	Normalized Weight
Lineament	0.39	0.41	0.40	0.35	0.38	0.3892
Slope	0.20	0.21	0.20	0.24	0.23	0.2141
Rainfall	0.20	0.21	0.20	0.24	0.15	0.1987
Lithology	0.13	0.10	0.10	0.12	0.15	0.1213
Drainage	0.08	0.07	0.10	0.06	0.08	0.0767
Column Total	1.00	1.00	1.00	1.00	1.00	1.00

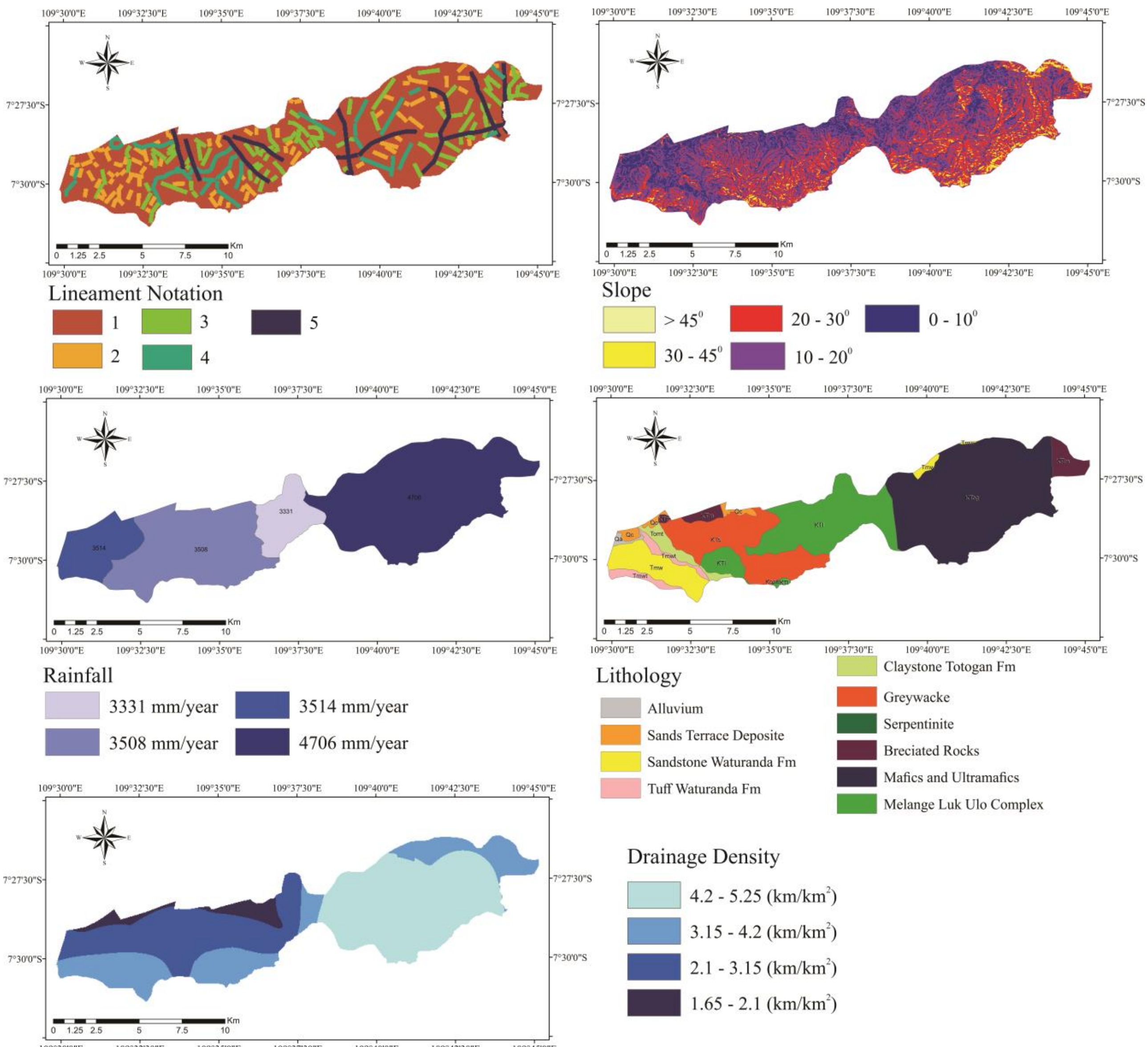

Figure 3. All five thematic maps and its classes

Table 3. Assigned rank for various classes of all thematic layers

Factors	Weight	Class	Groundwater storage potential	Assigned Rank
Lineament	0.3892	No lineament	Very Low	1
		Fractures, short lineament	Low	2
		Local faults, frequent fractures	Moderate	3
		Interconnected local faults, frequent faults	High	4
		Major long faults	Very High	5
Slope	0.2141	$>45^0$	Very Low	1
		30^0-45^0	Low	2
		20^0-30^0	Moderate	3
		10^0-20^0	High	4
		0^0-10^0	Very High	5
Rainfall	0.1987	3000-4000 mm/year	High	4
		4000-5000 mm/year	Very High	5
Lithology	0.1213	Mélange Luk Ulo Complex, Serpentinite, Mafic and Ultramafic and Brecciated Rocks	Very Low	1
		Claystone Totogan Fm Tuff Waturanda Fm	Low	2
		Greywacke	Moderate	3
		Sandstone Waturanda Fm	High	4
		Quaternary Terrace Deposit Alluvium	Very High	5
Drainage	0.0767	4.2-5.25 km/km^2	Very Low	1
		3.15-4.2 km/km^2	Low	2
		2.1-3.15 km/km^2	Moderate	3
		1.65-2.1 km/km^2	High	4

221 lineaments were identified from DEM data. Then, all lineaments were processed using buffer tools with the total width of 250 meters. Buffering of 250 meters width was conducted based on background fracturing zone according to fault zone model by Braathen & Gabrielsen (2000) [53]. Each lineament buffer zone was given a rank of 1-5 based on interpretation of its capacity to promote groundwater occurrence. Major long faults were given the highest rank of 5. Interconnected local faults and frequents faults were attributed with rank of 4. Local faults and frequent fractures were given the moderate rank. While, fractures and short lineaments were attributed with rank of 2 as they were believed as low groundwater storage potential. Lastly, area of no lineament were given the lowest rank of 1.

Slope of study area was classified into 5 classes as 0^0-10^0, 10^0-20^0, 20^0-30^0, 30^0-45^0, and $>45^0$. Groundwater potential occurred in gentle slope to plain region as water flow is slow and the time is enough available to improve the infiltration of water to the underlying fractured aquifer [47]. Therefore, lower degree of slope was given higher rank than higher degree of slope. Slope of 0^0-10^0 was given the highest rank of 5. Whereas, slope of more than 45^0 was given the lowest rank of 1.

Rainfall data of study area was obtained from BPS-Statistics of Banjarnegara. There are several limitation of rainfall of study area as follows (1) the location of rainfall station were unknown, (2) rainfall data were attributed based on administrative area of the sub-district, (3) only one of 4 sub-district which has complete annual rainfall data from the year of 2007 until 2016. There are 4 sub-district in the study area, Pagedongan sub-district which is located in the easternmost of the study area, Mandiraja sub-district which is located in the westernmost of the study area, Bawang sub-district which in the mid east, and Purwanegara sub-district which is located in the mid west. Pagedongan sub-district has average of annual rainfall of 4706 mm/year. Average of annual rainfall of 3331 mm/year was recorded in the Bawang sub-district. While, Purwanegara sub-district has average of annual rainfall of 3508 mm/year. Lastly, Mandiraja sub-district has average of annual rainfall of 3514 mm/year. Rainfall was classified into 2 classes, 3000-4000 mm/year which is given rank of 4, and 4000-5000 mm/year which is attributed with rank of 5 as expected to have highest groundwater potential.

Melange Luk Ulo Complex, Serpentinite, Mafic and Ultramafic, and Brecciated Rocks which were consisted of metamorphic and igneous rocks were attributed as the lowest groundwater potential due to lower permeability. Claystone Totogan Formation and Tuff Waturanda Formation were given rank of 2. Greywacke as the member of Luk Ulo Complex was given moderate rank of 3. While, Sandstone Waturanda Formation was attributed with rank of 4. The highest rank was assigned to Quaternary Terrace Deposits and Alluvium.

Drainage density of the study area ranging from 1.65 km/km2 to 5.23 km/km^2. Therefore, drainage density of the study are was classified into 4 classes: 1.65-2.1, 2.1-3.15, 3.15-4.2, and 4.2-5.25 km/km^2 as shown in Figure 3. The highest drainage density appeared in the eastern part of the study area. Higher drainage density were given lower rank, while lower drainage density were given higher rank. Hence, 4.2-5.25 km/km^2 was given the lowest rank of 1. Whilst, 1.65-2.1 km/km^2 was given rank of 4.

4.2 Groundwater Potential Zones Map

The systematic AHP analysis on weighted factors generated a groundwater potential zones map using raster calculator tool in ArcGIS software by integrating all thematic maps. The index of groundwater potential is ranging from 1.79 to 4.72. The classification of groundwater potential zone is based on equal interval method. Hence, the interval of 1-1.8, 1.8-2.6, 2.6-3.4, 3.4-4.2, and 4.2-5.00 is assigned to very low, low, moderate, high, and very high. Groundwater potential zones map is presented in Figure 4.

The groundwater potential zone at a glance is highly reflects lineament layer map. Almost to none of the study area is classified as very low groundwater potential zone. This class only covered a pixel which equivalent to area of 1529 m^2. The study revealed that 43.02% (37.12 km^2) of the study area exhibits poor groundwater potential zones (Table 4). Poor groundwater potential zone is the largest index in the study area. Poor groundwater potential zone is characterized by having no lineament zone, slope more than 20^0, lithology Melange Luk Ulo Complex, Serpentinite, Mafic and Ultramafic, Brecciated Rocks, Claystone Totogan Formation, and Tuff Waturanda Formation; and higher drainage density. Those rock assemblages consist of metamorphic rocks (amphibolite, serpentinite, schist and phyllite), igneous rock (granite, porphyry, gabbro, and basalt), and sedimentary rocks such as tuff, claystone, and shale.

17.98% (15.52 km^2) of the study area was classified as having high to very high groundwater potential zones. While moderate groundwater potential zone covered 38.99% (33.65 km^2) of the study area. The presence of high to very high groundwater potential zone may pertain to the presence of interconnected local faults, frequent faults, and major long faults; greywacke, alluvium and quaternary unconsolidated terrace deposit, higher rainfall, gentle slope below 20^0, and lower drainage density.

Table 4. Classification of groundwater potential zone

Groundwater Potential Zones	Area (%)	Area
Very High	1.18	1.02 km^2
High	16.80	14.49 km^2
Moderate	38.99	33.65 km^2
Low	43.02	37.12 km^2
Very Low	0.00	1529 m^2
Total	1.00	115.89

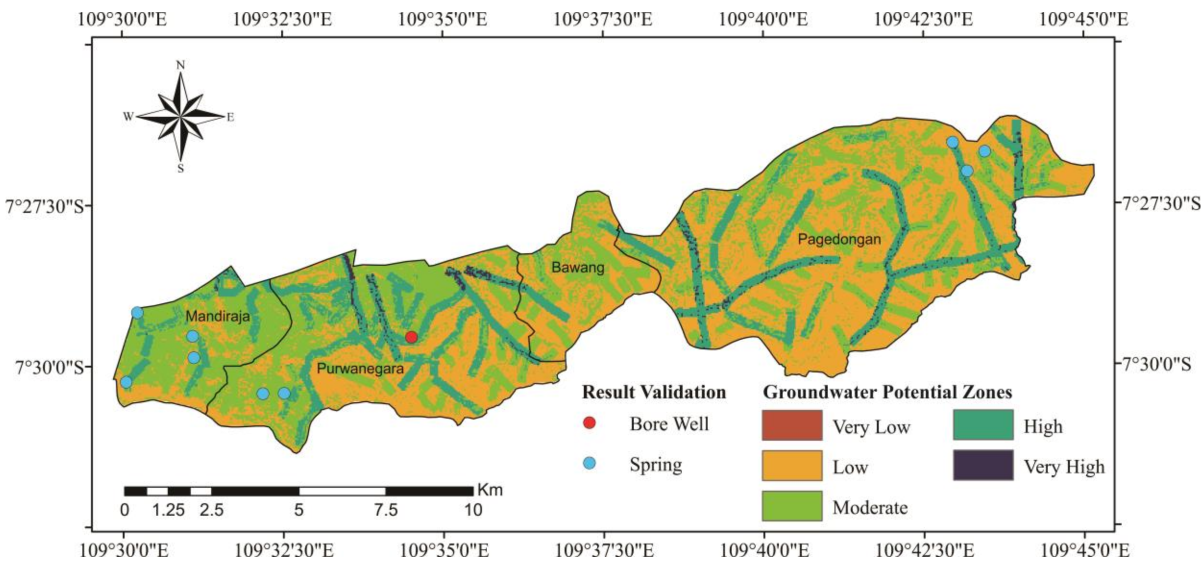

Figure 4. Groundwater potential zones map

4.3 Result Validation

The occurrence and discharge of springs and bore wells were used for validation of groundwater potential map. Firstly, there are 52 springs and 2 bore wells in the study area which were discovered during the observation in the dry season of 2018. However, there are only 9 springs and 1 bore wells where appropriate measurement of discharge were conducted. The discharge of springs and bore wells ranging from 0.12 l/s to 2 l/s. This range of springs discharge is classified as sixth magnitude springs based on classification of springs by discharge according to Meinzer [53]. While, bore well yield of 2 l/s.

Based solely on the occurrence of springs and bore wells, 1 spring and 1 bore well are located in very high GPZ, 9 springs and 1 bore well in high GPZ, 30 springs in moderate GPZ, and 12 springs in low GPZ. While, no spring in very low GPZ. 30 springs are located in lineament zone. Apparently, high to very high GPZ and occurrence of springs correspond to lineaments.

The correlation of AHP raster values to the corresponding discharge of springs and bore wells showed a positive coefficient of determination (R^2) of 0.80 (Figure 5). It shows that the groundwater potential zones map which was generated by using integration of RS, GIS, and AHP technique in the research area have a promising result.

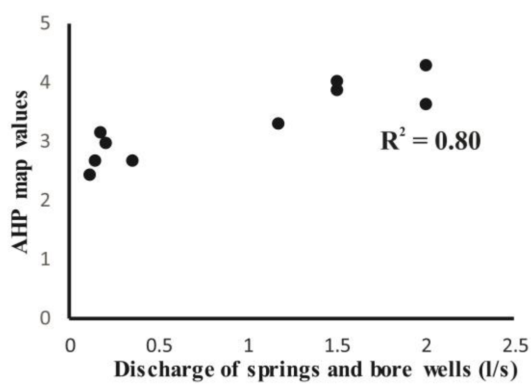

Figure 5. Plot of the AHP raster value to the corresponding discharge of springs and bore wells

5. CONCLUSIONS

The application of remote sensing, GIS, AHP is demonstrated as useful tools and cost effective method for delineation of groundwater potential zones. Groundwater in the study area is mainly controlled by lineament, slope, rainfall, and lithology factors. While, drainage is the secondary factors. Groundwater potential in the study area is classified into five: very low, low, moderate, high, and very high groundwater potentials cover 1529 m^2 (0.00%), 37.12 km^2 (43.02%), 33.65 km^2 (38.99%), 14.49 km^2 (16.80%), and 1.02 km^2 (1.18%) of study area respectively. High to very high GPZ are characterized by the presence of interconnected local faults, frequent faults, and major long faults; greywacke, alluvium and quaternary unconsolidated terrace deposit, higher rainfall, gentle slope below 20^0. Evaluation using discharge of springs and bore wells denoted that the result of groundwater potential zones map is promising as the coefficient of determination (R^2) of 0.80. This GPZ map can be a guide and basis information for local authorities and planners about the favorable area for prospective exploration of groundwater.

ACKNOWLEDGEMENT

The authors sincerely acknowledge “Agency of Planning, Research and Development of Banjarnegara Regency” and “PAMSIMAS Banjarnegara” for their kind and generous support in presenting needed data and maps. The authors also would like to express gratitude to Thema Arrisaldi and Raja Susatio in supporting maps and assisting the GIS processing.

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