Analysis of groundwater recharge zone using remote sensing method in Bayah Region

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Abstract. Groundwater is one of the most important natural resources. Based on population needs, groundwater use meets around 60% for irrigation, industry, drinking water, sanitary facilities, etc. Based on data from the DESDM of Banten Province (2016), the Bayah Sub district area belongs to a small productive aquifer and rare underground water. With the development of in the Bayah region, it will be necessary to have a spatial with environmental insight. One of the important things in determining environmentally planning is by determining groundwater recharge areas in the area. The method used in this study is the Remote Sensing method. Data sources which used here is geological maps, DEMNAS imagery, Landsat-8 imagery, Landsat-5 TM imagery, Bayah rainfall stations. These data are processed using GIS to produce thematic maps such as lithology maps, land cover, lineament density, drainage density, rainfall, slope, and geomorphology. Scoring of all thematic maps is done using the multi-criteria evaluation / analysis method based on the superiority of each thematic map and the data in the thematic map itself on groundwater recharge value. The results of scoring on each thematic map are then overlaid on each thematic map to produce a map of potential groundwater recharge. According to this study the research can conclude that remote sensing and multi criteria evaluation can effectively use for finding groundwater recharge potential by using those 7 thematic maps. The study area mostly has high value groundwater potential recharge (2-3) which is 109,17 km² and 77% of the study area.

1. Introduction

Groundwater is one of the most important natural resources. Based on the needs of the population, the use of groundwater is around 60% for irrigation, industry, drinking water, sanitary facilities, etc. [1]. Based on the source, ground water comes from surface water (rainwater, lakes, etc.) then percolate into the ground towards to the aquifer in the recharge area and flows into the discharge area [2].

Bayah is a sub-district located in Lebak Regency, Banten Province shown in Fig 1. Based on data from the DESDM of Banten Province, Bayah Subdistrict is included in small productive aquifers and has rare underground water. Bayah itself has tourism potential that has been developed by the Banten Government [3]. With the development of tourism in the Bayah region, it will be necessary to have a spatial layout that are expected not only to be concerned with profit but also with environmental insight [1]. One of the important things in determining environmentally insight spatial planning is by determining groundwater recharge areas in the area, considering groundwater or aquifers in the Bayah region itself which has small and rare productions [3].
Determination of potential groundwater recharge areas is carried out by using remote sensing which produces a map of potential groundwater recharge areas [4]. Geospatial devices like RS and GIS are viable instruments for breaking down voluminous geomorphic, geologic and hydrological information and for demonstrating of complex features in decision making level [5]. Remote sensing satellites provide opportunities for better observation and more systematic analysis of various geomorphic units/landforms/alignments due to the synoptic and multi-spectral coverage of a field [4]. Investigating remote sensing data for drainage maps, geology, geomorphology and lineament in an integrated manner facilitates an effective evaluation of the determination of groundwater potential zones [4] also LULC, slope, and rainfall data commonly were used for the analysis [5]. Information from the map is expected to be utilized in an environmentally insight layout.

![Figure 1. Map showing the location of the study area.](image)

2. Methods
The method in this study is done by making thematic maps of each parameter used, weighting of each variable in thematic maps based on their influence on groundwater recharge, and the ranking of each thematic map based on the dominant influence on groundwater recharge, then the weighted linear combination method is carried out from the seven thematic maps to obtain groundwater recharge values. The rank of each thematic in this study is calculated from previous research.

2.1 Thematic Map Preparation
Data used in making thematic maps are using Landsat imagery from Landsat-8 (July 2018) and Landsat-5 satellites (October 2016), rainfall station and lithology samples in the field, geological maps, administrative data and DEM data from DEMNAS. Thematic rainfall maps were made using ArcGIS by inputing rainfall station points and interpolating to produce annual rainfall distribution per year.
Thematic slope maps is done using ArcGIS by entering DEMNAS data and doing a Slope (Spatial Analyst).

The distribution of lithology is obtained by digitizing the leuwidamar geological map of sheets of 1:100,000 scale which covering all the research coverage areas using ArcGIS. After digitizing, lithology data is strengthened by processing landsat TM-5 data in the research area by displaying the false color composite using a composite band from the data in ArcGIS and lithology samples in the field. Geomorphology was obtained by displaying slope data, topography, river flow patterns and lithology, from the data then reclassification is based on landform using the van Zuidam classification.

Lineament density is obtained by doing automatic lineament extraction in landsat-8 using band 8 (panchromatic band) and manual correction using DEMNAS data, after the lineament distribution was obtained in the study area, a Line Density (Spatial Analyst) tool was used to obtain lineament density. Drainage density is obtained by processing DEMNAS data to describe the river network using the Flow Accumulation tool and Stream Feature. River networks are used to obtain drainage density by using of Line Density (Spatial Analyst) tools. Thematic maps of LULC were obtained by processing landsat 8 data showing a false color composite using a composite band with a band ratio RGB 5/4/3. The next step is to classify each land cover based on the colors displayed in ArcGIS, classification is done by using the Image Classification Toolbar to define each land cover.

2.2 Multi-criteria Analysis
The method used in weighting MCA is the Weighted Linear Combination. MCA is a method commonly used in calculating index values. The weighted linear combination method involves a three-stage evaluation. First, the relative importance of each parameter, or factor, is evaluated against other criteria. The criteria weight is displayed in 0 - 1.0. Second, data or indicators for each parameter are given weight based on knowledge and expertise in their fields [6]. Third, the data is merged to obtain the potential value of groundwater recharge [7]. Weighted Linear Combination method done by using the Weighted Overlay tool with the formula:

\[ GP = \sum_{i=1}^{n} W_i . X_i \]  

Where GP = groundwater potential, Wi = weight / rank for each thematic map and Xi = weight for indicators on thematic maps [7].

| Table 1. Ranking for each thematic map from previous research and ranking calculation on this study |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Lithology | Geomorphology | Lineament Density | Drainage Density | LULC | Slope | Rainfall |
| Ferozur [5] | 0.37 | 0.15 | 0.24 | 0.07 | 0.02 | 0.11 | 0.04 |
| Singh [8] | 0.22 | - | - | 0.125 | 0.2 | 0.16 | - |
| Rajaveni [9] | 0.1 | 0.25 | 0.2 | 0.2 | 0.15 | 0.1 | - |
| Fenta [7] | 0.38 | 0.16 | 0.24 | 0.06 | 0.02 | 0.1 | 0.04 |
| Suganthi [10] | 0.20 | 0.25 | 0.10 | 0.10 | 0.10 | - | 0.10 |
| Total | 1.27 | 0.81 | 0.78 | 0.555 | 0.49 | 0.47 | 0.18 |
| Mean | 0.254 | 0.2025 | 0.195 | 0.111 | 0.098 | 0.117 | 0.06 |
| \( \sum \) Mean | 1.038 |
| Rank (\( \sum =1 \)) | 0.25 | 0.20 | 0.19 | 0.11 | 0.09 | 0.11 | 0.05 |
Based on the table, groundwater recharge potential will be calculated following the formula:

\[
GP = 0.25 \times \text{Lithology} + 0.20 \times \text{Geomorphology} + 0.19 \times \text{Lineament Density} + 0.11 \times \text{Drainage Density} + 0.09 \times \text{LULC} + 0.11 \times \text{Slope} + 0.05 \times \text{Rainfall}
\]  

(2)

3. Results and Discussion
The following is the result of processing all the thematic map parameters and their weighting based on their influence on groundwater recharge values.

Figure 2. Thematic map for  
(a) Rainfall  
(b) Drainage Density  
(c) Lineament Density
Figure 3. Thematic map for a.) LULC; b.) Slope; c.) Geomorphology; d.) Lithology
| Parameter         | Range | Score | Distribution | Percentage |
|-------------------|-------|-------|-------------|------------|
| Lithology         | Alluvium | 5     | 3.5 km$^2$  | 2.4        |
|                   | Igneous Rocks | 1     | 5.25 km$^2$ | 3.6        |
|                   | Limestone   | 2     | 20.26 km$^2$| 15         |
|                   | Breccia     | 4     | 12.84 km$^2$| 8.9        |
|                   | sandstone   | 3     | 60.67 km$^2$| 42         |
|                   | claystone   | 1     | 2.86 km$^2$  | 2.4        |
|                   | Tuff        | 4     | 38.06 km$^2$ | 26        |
| Geomorphology     | Denudational Hills | 2     | 3.9 km$^2$  | 2.7        |
|                   | Fluvial Plains | 5     | 17.92 km$^2$| 12.4       |
|                   | Karst Hills  | 3     | 17.02 km$^2$| 11.2       |
|                   | Volcanic Intrusion | Hills | 1    | 6.87 km$^2$ | 5         |
|                   | Low Volcanic Hills | 4     | 8.23 km$^2$ | 5.7        |
|                   | Sedimentary Hills | 4     | 11.94 km$^2$| 8.3        |
|                   | High Volcanic Hills | 3    | 23.55 km$^2$| 16.4       |
|                   | Structural Hills | 2     | 54.13 km$^2$| 37.7       |
| Slope             | 0 - 5       | 5     | 23.48 km$^2$| 16.3       |
|                   | 5 - 10      | 4     | 26.01 km$^2$ | 18.1       |
|                   | 10 - 15     | 3     | 36.22 km$^2$ | 25.2       |
|                   | 15-25       | 2     | 37.35 km$^2$ | 26.1       |
|                   | >25         | 1     | 20.46 km$^2$ | 14.3       |
| LULC              | Water Bodies | 5     | 1.7312 km$^2$| 1.2        |
|                   | Forest/bush | 2     | 100.79 km$^2$| 70.5       |
|                   | Agricultural Land | 3     | 29.907 km$^2$| 20.8       |
|                   | Settlement  | 1     | 9.3717 km$^2$| 6.5        |
|                   | Bareland    | 4     | 1.6962 km$^2$| 1          |
| Drainage Density  | 0 - 1.284   | 5     | 1 km$^2$    | 0.7        |
|                   | 1.284 - 2.569 | 4     | 9 km$^2$   | 6.3        |
|                   | 2.569 - 3.854 | 3     | 42 km$^2$  | 29.4       |
|                   | 3.854 - 5.138 | 2     | 61 km$^2$  | 42.6       |
|                   | 5.138 - 6.423 | 1     | 30 km$^2$  | 21         |
| Lineament Density | 0 - 0.845   | 1     | 72 km$^2$  | 50         |
|                   | 0.845 - 1.691 | 2     | 41 km$^2$ | 28         |
|                   | 1.691 - 2.537 | 3     | 23 km$^2$ | 16         |
|                   | 2.537 - 3.382 | 4     | 7 km$^2$  | 5.3        |
|                   | 3.382 - 4.228 | 5     | 1 km$^2$   | 0.7        |
| Rainfall          | 149 mm     | 2     | 153 km$^2$ | 100        |
3.1 Slope
Based on the slope map, the weighting is done at the values 0-5, 5-10, 10-15, 15-25, >25 degrees. Weighting criteria are carried out based on the slope value, the higher the slope value the lower the weighting due to the increase in run-off of water on the surface [5]. Based on its distribution, the slope in the Bayah sub-district is dominated by the slope values of 10-15 degrees and 15-25 degrees by 25.2% and 26.1%, while the lowest slope spread is at a value of > 25 degrees at 14.3%. The distribution shown in Figure 3(b) and Table 2.

3.2 Land use/Land cover
Land cover is classified into 5 groups, which are water bodies, forests/shrubs, agricultural land, settlements and barren land. weighting is done on land cover types, water bodies, forests, rice fields, settlements, and open land based on the evapotranspiration and followed by the runoff value [8]. The LULC indicator is sorted by the weight from the highest to the smallest water bodies > wasteland > agricultural area > forest > settlement. Weight is obtained based on previous research. Agricultural land have a score of 3 because the irrigation process depends on groundwater other than rainfall [9] and the evapotranspiration process tends to be low. Forest has a score of 2 due to the high evapotranspiration process in the environment causing the water to return to the air [8] [11]. Settlements have the lowest score because surface water in residential environments has slow percolation and tends to trap water on the surface of the type of land cover [8]. The distribution shown in Figure 3(a) and Table 2.

3.3 Drainage density
Drainage density used as the criteria for determining the potential of groundwater recharge based on the value of drainage density in the study area. The greater the drainage density value, the lower the potential for groundwater recharge value due to the high value of drainage density indicating the run-off value in the area [7][9]. Based on the results of processing the drainage density map, five classes were obtained with values 0-1.284 km², 1.284-2.569 km², 2.569-3.854 km², 3.854-5.138 km², 5.138-6.423 km². Scores are carried out sequentially from the lowest drainage density value of 5 to the highest of 1. Classification is done using equal interval. The distribution shown in Figure 2(b) and Table 2.

3.4 Lineament density
Lineament density used as the criteria for determining the potential of groundwater recharge based on the value of lineament density in the study area. The greater the lineament density value means the highest potential for groundwater because lineament density indicates the number of structures and acts as secondary permeability in the area [9]. Based on the results of processing drainage density maps, five classes were obtained with values 0-0.845 km², 0.845-1.691 km², 1.691-2.537 km², 2.537-3.382 km², 3.382-4.228 km². Scores are carried out sequentially from the lowest lineament density value of 1 to the highest of 5. Classification is done using equal interval. The distribution shown in Figure 2(c) and Table 2.

3.5 Lithology
Thematic maps of lithology are obtained from the results of processing geological map data, Landsat 5 TM, and rock samples in the field. In Landsat 5 TM data band composite is performed with a combination of RGB 4/2 5/3 4/3. This combination produces colour that can distinguish several types of rocks [12]. The contrasting colour of the band combination shows the colour of karst limestone and alluvium, while other lithology (sandstone, tuff, breccia, and igneous rock) are less distinguishable from these combinations so that field data and geological maps are used to complement lithological thematic maps.

Based on the results of processing data from geological maps, Landsat 5 TM and lithology samples in the field, obtained a thematic map of lithology with seven lithology units which are; alluvium, igneous rocks (basalt, andesit), limestone, breccia, sandstone, claystone, and tuff. Scoring on thematic maps is done based on the permeability classification of each rock from [13]. The higher the permeability
ability of rocks to pass water, the higher the score on the value of groundwater infiltration. Lithology is grouped for scoring based on the hydraulic conductivity value of each rock. The lithology of clay, basalt and crystalline stones was included in the score 1, the limestone was put into a score of 2, the sandstones were put into the score 3, the tuff and breccia were put into the score 4, the alluvium deposits were added to the score 5. The distribution shown in Figure 3(d) and Table 2.

3.6 Geomorphology
Geomorphological thematic maps are obtained based on data analysis by following classification from van Zuidam [14]. The data used are relative height values and drainage patterns of the study area based on DEMNAS data, lithology and the structure of the study area based on the geological map of the Leuwidamar sheet. Based on the geomorphological classification of the study area, eight geomorphological units were obtained, which are, Denudational Hills, Fluvial Plains, Karst Hills, Volcanic Intrusion Hills, Low Volcanic Hills, Sedimentary Hills, High Volcanic Hills, Structural Hills [15]. Scores of each geomorphological unit from highest to lowest shown in Table 2.

Denudational hills are the result of erosion and weathering, based on their ability to infiltrate surface water which tends to be low [16], with the result that put in score 2. Fluvial plains have high potential groundwater recharge because of the flat landforms and rock material that supports surface water entering the soil [16] and scored to 5. Karst hills has the potential for intermediate groundwater absorption because water moves depending on the dissolved zone in the karst area. Volcanic intrusion hills have the lowest score because they are composed of impermeable rocks so that the potential of surface water entering the soil tends to be low and has rare groundwater [16]. Structural hills have a score of 2 because the structural hills zones tend to be unfractured so that they have low water absorption capabilities [9]. Low volcanic hills and sediment hills has a score of 4 because the landform has good water absorption capability [17]. The distribution shown in Figure 3 (c) and Table 2.

3.7 Rainfall
Based on BMKG data, the average monthly rainfall (1981-2010) in the Bayah area is 149 mm. which considered as under normal. Scoring is carried out on the value of rainfall in the study area. Based on the rainfall value, the rainfall score in the Bayah area is 2 because the rainfall is grouped under normal. The distribution shown in Figure 2(a) and Table 2.

3.8 Groundwater recharge potential map
Based on the results of processing seven thematic maps using the weighted overlay method in ArcGIS, the distribution of potential groundwater recharge values was obtained. The potential for very low groundwater recharge has a total value of less than 1, the potential for low groundwater recharge has a total value of between 1 to 2, the potential for high groundwater recharge has a total value of 2 to 3, and the potential for very high groundwater recharge has a total value between 3 to 4. Based on the distribution, the potential value of groundwater recharge is dominated by high potential covering an area of 109.17 km2 and 77% of the research area, followed by low potential value with an area of 27.06 km2 and 19% of the research area, the potential is very high and the area 5.40 km2 and 3.8% of the study area, and the potential value is very low with an area of 0.21 km2 and 1.4% of the study area. The distribution shown in Figure 4.

Based on the potential value of groundwater recharge (Figure 4.), the potential for groundwater recharge with very high values is generally influenced by alluvium lithology and fluvial geomorphology while the potential for low-very low groundwater infiltration is generally influenced by limestone, clay and igneous lithology and denudational geomorphology, karst and volcanic intrusion. Both values also influenced by the lineament density, drainage density, slope, LULC, and rainfall.
4. Conclusion
According to this study, the research can conclude that remote sensing and multi criteria evaluation can effectively use for finding groundwater recharge potential by using those 7 thematic maps. The study area mostly has high value groundwater potential recharge (2-3) which is 109.17 km² and 77% of the study area. Finally, author hopefully that this study can be used for groundwater conservation and development on the study area.

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