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Identification of recharge area in Bengawan Solo Indonesia catchment areas based on Geographic Information System

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Abstract. To be able to assess or determine the recharge area, several parameters are needed. Until now, the criteria/parameters for determining the recharge area are still not standard and varied to each local government. The results of the literature study obtained 14 variables that can be used to determine the recharge area. These 14 variables, called longlist of variables, are then discussed with experts to determine the dominant variables to be used. The main variables for the determination of the recharge area are geological conditions, surface soil type, rainfall, and slope conditions. Each variable has a different influence weight depending on the condition of the region with the dominant factor is the geological condition. In the case of Bengawan Solo Catchment Areas, the weight of each variable was: geology (40%), surface soil type (30%), rainfall (20%), and slope (10%); The class range of each variable can vary depending on the condition of the study area. All of this data is processed with the Geographic Information System for analysis. It can be concluded the recharge area has the main characteristics of having a general direction of groundwater flow vertically downward, rock outcrops escape water-unsaturated water, hills or mountainous areas, volcanic body areas and cone peaks, and karst areas that have cracks and dissolution holes.

1. Introduction

Recharge area is the area of water entering from the ground surface into a water-saturated zone to form a flow of ground water flowing to a lower area. This area is very important for the sustainability of the hydrological cycle. The existence of water is strongly influenced by changes in land use in recharge areas. In other words, land use change affects the availability and needs of water. For example, when a forest area in a recharge area changes to a settlement, the water needs increase because it is used for residents in the settlement, but the availability of water is reduced because the recharge area is reduced.

When the land in the recharge area changes, there will be an increase in surface flow. As a result, downstream get excessive discharge and the impact is flooded. Land changes also cause land erosion. When the land changes, there is an increase in surface flow and water cannot be retained in the watershed. As soon as it rains all flows into the river so that droughts increase in the dry season. When the discharge increases, the flow of the river with a large discharge will also bring large sediments so that the capacity of the river is reduced and at the terminal end the journey of water in the river is at the mouth of siltation [1]. In addition, the recharge area is also a contributor to ground water conservation [2], [3], [4].

2. Literature Review

Several studies on the importance of the role of recharge areas [5], [6] revealed that recharge areas are needed in the management of groundwater and water quality. Thus, identification of recharge areas is important to be used for planning in water resources management. Several studies on the determination of potential recharge areas have been carried out by several researchers. For example, [7] using raster data and overlaid with variable types and weights are 20% slope, 25% geomorphology, 20% soil, 25% land use/land cover, 5% drainage density, and 5% lineament density. Furthermore, [8] used the Analytical Hierarchy Process (AHP) and GIS methods to identify recharge areas by considering 11



variables. Meanwhile, [9] were using 8 variables (SLUGGER-DQL - Soil (S), Land Use (LU), Geomorphology (G), Geology (GE), Well Density (D), Water Quality (Q), Depth of Groundwater (L)) in determining the recharge area with the help of GIS with raster model data and weighting each variable.

From the review of previous research, it can be concluded that to determine the recharge area, several parameters are needed. Each researcher has their own assumptions about these parameters. While at the institutional level, until now the criteria/parameters for determining the recharge area still have no default standards and are generally handed over to each local government. Standard criteria need to be set, at least as a reference for local governments to zoning areas that have the potential to absorb water into the soil. It is important since the function of the recharge area, in addition to increasing groundwater reserves, also serves to reduce the potential for possible flooding.

So that in this study, the parameters for determining water catchment areas were reviewed from several previous studies [10], [11] and several regulations which have existed both locally and abroad. Some parameters that have been collected are as described in Table 1 and will be discussed in the next section and implemented with data from the Bengawan Solo river basin as the research sample area.

Table 1. Parameters for determining recharge areas from previous studies

No	Parameter	TCEQ Regulator Guidance (2005)	(Ham mouri et al. 2014)	(Kaliraj, Chandrasek ar and Magesh 2014)	(Patil and Mohit 2014)	(Pala ka and Sank ar 2015)	Perme n PUPR 10/PR T/ M/2015
1	Drainage Density (km/km ²)			✓	✓	✓	
2	Land Use/Land Cover	✓	✓	✓	✓	✓	✓
3	Lineament Density (km/km ²)			✓	✓	✓	
4	Geomorphology	✓	✓	✓	✓	✓	
5	Slope (degree)			✓	✓		✓
6	Soil permeability (in m/day (vertically))	✓	✓	✓	✓		✓
7	Soil texture (grain size in mm)			✓			
8	Soil depth (in meter (vertically))			✓			
9	Rain Fall (mm)			✓			✓
10	Geology		✓	✓			
11	Aquifer transmissivity (m ² /day)			✓			
12	Well Density		✓				
13	Water Quality		✓				
14	Depth of Ground Water		✓				

The results of the literature study obtained 14 variables that can be used to determine the recharge area. These 14 variables, called the longlist of variables, will be discussed with these experts to determine the dominant variables to be used.

3. Methods

3.1. Determination of Selected Variables and Weighting Identification of Water Absorption Areas

The results of the discussion of the dominant variables by the expert, agreed upon 5 main variables that will be used to determine the recharge area. Some candidate variables are simplified into one variable, for example drainage density, lineament density, geomorphology, and geology can be represented by one variable, namely geological variables. The results of variable simplification can be seen in Figure 1.

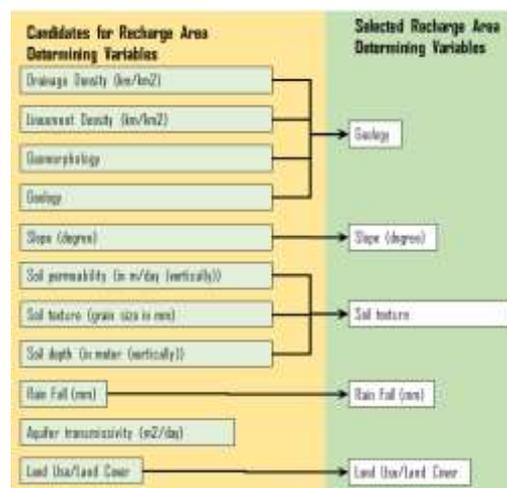


Figure 1. Simplifying the variable determinant of the recharge area (*shortlist variable*)

The level of influence of each variable is given in a weight value (in percent). The highest weight is the geological variable (40%), and the lowest is the slope (10%). Land use variables are not included in the recharge area determinant variable. This is done because if the land use variable is directly used as a determining variable for the recharge area, there will be a bias in the results of the analysis. For example, if the land use variable of the settlement is included as a recharge area variable, the area will obviously be an area that does not absorb water because it has been closed by the settlement, even though there are likely to be many settlements in the recharge area.

Overlay between variables will be carried out with the help of a Geographic Information System (GIS) in accordance with Figure 2. Weightings are used in mathematical formulations to get the final score.

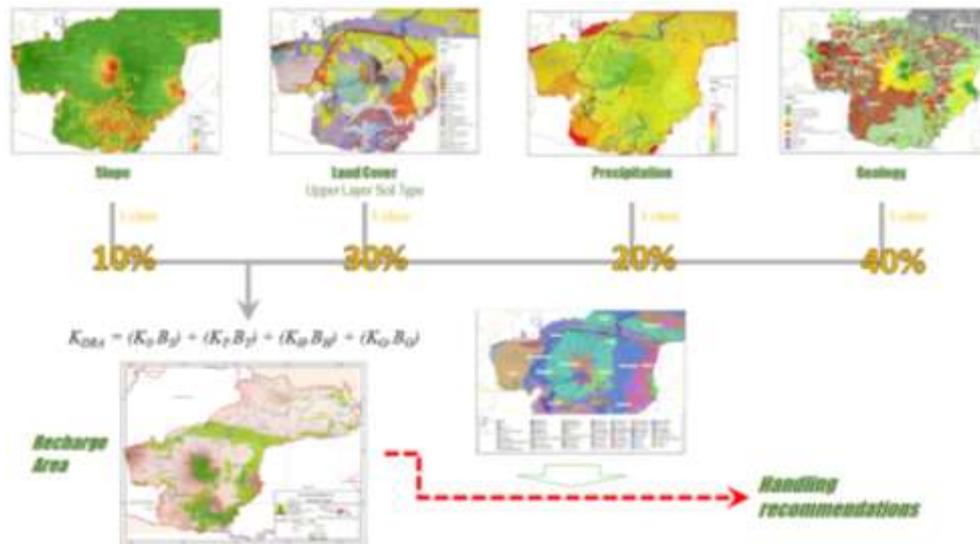


Figure 2. The process of overlaying between the main variables and overlaying the recharge with land use for handling recommendations

3.2. Classification of Each Selected Variable

The classification of each selected variable will use an ordinal variable model, which is a variable that is arranged based on levels in certain attributes. The highest level is usually given the number 1, the level below it is given the number 2, then below it is given the number 3 and so on, or vice versa. This method is called ranking. In this study, we use the ranking or classification system as referenced in Table 2 (Department of Energy and Mineral Resources, Geological Agency 2004).

Table 2. Classification of variables used

Rank	Ability to absorb water
5	Very High
4	High
3	Medium
2	Low
1	Very Low

4. Results and Discussion

4.1. Classification of Geological Variables

Based on its geological conditions, the geological condition rating is distinguished based on the value of water infiltration capability as in Table 3.

Table 3. Permeability and the score of each type of rock

Permeability (m/day)	Example	Ranks	Notes
103	Alluvial Deposits	5	Very High
101 – 103	Old Quarter Deposits	4	High
10-2 – 101	Young Quarter Deposits	3	Medium
10-4 – 10-2	Tertiary Deposits	2	Low
< 10-4	Intrusive Rock	1	Very Low

Summarized from various sources and main sources: Department of Energy and Mineral Resources, Geological Agency, 2004

Based on geological conditions from the source of the geological map, then an assessment by geologists (expert justice) is done to get the ranking value of each type of geological condition as in Table 4.

Table 4. Class/type of geological conditions

Ranks	Type of rock/formation
1	Alluvial and coastal deposits; Prupuh Limestone Members; Klitik Members; Ngrayong Members; Inseparable Volcanic Rocks; Coral Limestone; Baturetno Formation; Bulu Formation; Klitik Formation; Ledok Formation; Lidah Formation; Mundu Formation; Nglanggran Formation; Ngrayong Formation; Paciran Formation; Semilir Formation; Tambakromo Formation; Tuban Formation; Watupatok Formation; Wonocolo Formation; Wonosari Formation; Wungkal Formation; Lawu Lava
2	Old Alluvium; Alluvial; Bawah Members; Cendono Members; Dander Members; Napal Members; Alluvial Fan Deposits; Dayakan Formation; Kabuh Formation; Menuran Formation; Oyo Formation; Sampung Formation; Selorejo Formation; Coluvial; Dangean Morfonit; Ngebel Morfonit; Sedudo Morfonit; Patukbanteng-Jeding Morfoset
3	Top Members of the Kunjung Formation; Banyak Members; Tengah Members; Batuan Malihan; Terobosan Rocks; Undak Deposits; Jaten Formation; Nampol Formation; Wuni Formation
4	Top Members of the Angin Kalibeng Formation; Pandan Breccia; Dasit; Pendul Diorite; Old Merapi Vulcano Deposits; Lawu Deposits; Kalibeng Formation; Kalipucang Formation; Kebobutak Formation; Kerek Formation; Mandalika Formation; Notopuro Formation; Pucangan Formation; Sonde Formation; Argohalangan Morfoset; Butak Tuft
5	Anak Lava; Andesite; Lasem Andesite; Lawu Vulcano Rocks; Wilis Vulcano Rocks; Jobolarangan Breccia; Arjosari Formation; Dayakan Formation; Nglanggran Formation; Wonosari Formation; Butak Lava; Candradimuka Lava; Jobolarangan Lava; Sidoramping Lava; Sumbing Lava; Jobolarangan Tuft; Tambal Tuft

Spatial distribution of water absorption power based on geological conditions can be seen in Figure 3.

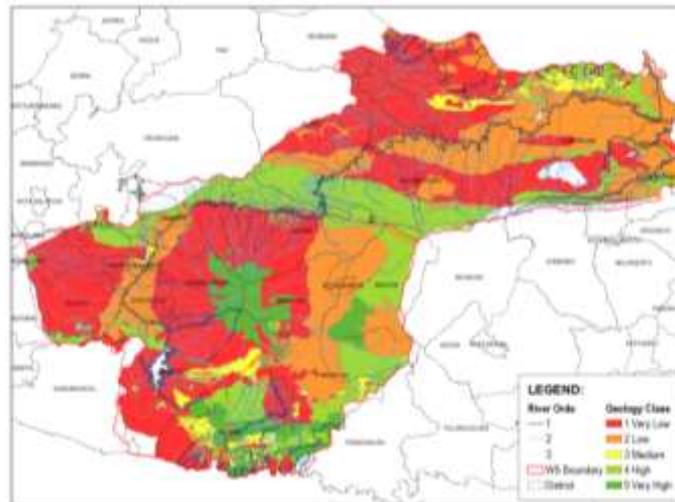


Figure 3. Water absorption on the geological condition of Bengawan Solo water basin

It can be seen in Figure 3 that some places that have high geological conditions are water absorbing districts that are in mountains and karst formations such as Pacitan, Karanganyar, Magetan, Ponorogo, Madiun and partly Ngawi, Blora, Ponorogo upstream.

4.2. Classification of Surface Soil Type Variables

Based on the condition of the soil type, the rating of soil type conditions is distinguished based on the value of the water infiltration capability based on the gradation of soil grains as in Table 5.

Table 5. Permeability and scores of each type of soil

Permeability (10^{-5} m/day)	Example	Ranks	Notes
> 30	Gravel	5	Very Fast
15 – 30	Sandy Gravel	4	Fast
7 – 15	Sandy Clay	3	Medium
2 – 7	Silty Clay	2	Slow
< 2	Clay	1	Very Slow

Summarized from various sources and main sources: Department of Energy and Mineral Resources, Geological Agency, 2004

Based on the condition of the soil type, the ranking of soil type conditions is distinguished based on the value of water infiltration capability as in Table 6.

Table 6. Soil type/classification

Ranks	Type of rock/formation
1	Gray Alluvial; Old Gray Alluvial; Gray Brown Alluvial; Hidromorf Alluvial; Gray Alluvial and Gray Brown Alluvial; Brown and Gray Brown Alluvial Association; Litosol Association and Old Gray Grumusol; Gray Brown and Yellowish Gray Grumusol; Gray Grumusol; Old Gray Grumusol; Gray Brown Regosol; Gray Regosol
2	Litosol and Brown Mediteran Association; Litosol and Reddish Brown Mediteran Association; Brown Mediteran Association Litosol; Reddish Brown Litosol Complex and Litosol; Litosol, Mediteran and Renzina Complex; Brown Mediteran Complex and Litosol; Reddish Brown Mediteran Complex and Litosol; Red

Ranks	Type of rock/formation
	Mediterranean Complex and Litosol; Brown Litosol; Reddish Brown Litosol; Yellowish Red Litosol; Litosol; Brown Mediterranean; Reddish Brown Mediterranean
3	Brown Andosol; Brown Andosol and Reddish Brown Latosol; Brown Andosol, Yellowish Brown Andosol, Litosol; Old Gray Andosol Complex and Litosol; Black Grumusol Complex and Litosol; Gray Grumusol Complex and Litosol; Reddish Brown Mediterranean and Gray Grumusol
4	Gray Andosol Association and Gray Regosol; Gray Brown Grumusol and Gray Yellow; Gray Grumusol; Old Gray Grumusol; Gray Regosol Complex and Old Gray Grumusol; Gray Regosol Complex and Litosol; Brown Latosol and Gray Regosol; Brown Regosol
5	Gray Brown Regosol; Gray Regosol

Spatial distribution of water absorption power based on soil type conditions can be seen in Figure 4. It can be seen in Figure 4 that some places that have high surface soil jens are water-absorbing districts in the mountains such as Karanganyar, Magetan, and Ponorogo Regencies.

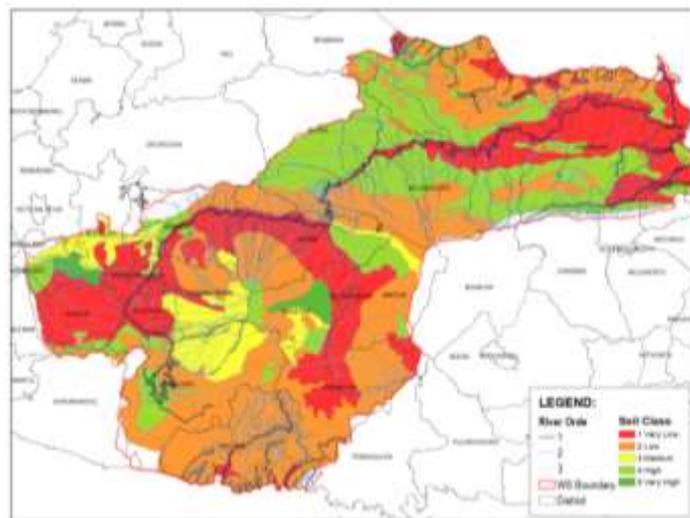


Figure 4. Water absorption on soil type conditions in the Bengawan Solo river basin

4.3. Classification of Rainfall Variables

Based on the conditions of rainfall, the rainfall condition rating is distinguished based on the value of the amount of rain as in Table 7. Rainfall is classified with a range of 500 mm, due to consideration of the minimum and maximum values of rain that occur in the study area.

Table 7. Rainfall classification

Rainfall (mm)	Ranks
>3.000	5
2.500-3.000	4
2.000-2.500	3
1.500-2.000	2
< 1.500	1

From Figure 5, it can be seen that the highest rainfall is on the slopes of Mount Lawu in the Karanganyar Regency.

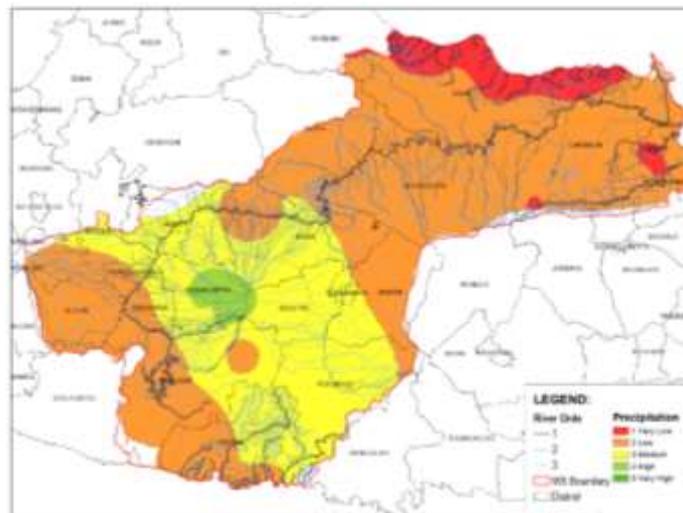


Figure 5. Results of assessment of rainfall in the Bengawan Solo river basin

4.4. Slope Variable Classification

Ranking on slope of land will be based on Table 8. Assuming that the more land has a high slope, the harder it will be to absorb it into the soil due to high runoff due to the influence of the slope.

Table 8. Land slope class

Slope (%)	Rank
< 5	5
5-20	4
20-40	3
40-60	2
> 60	1

The results of plotting conditions in the study area based on slope can be seen in Figure 6, most of the study areas (more than 70%) have a low slope.

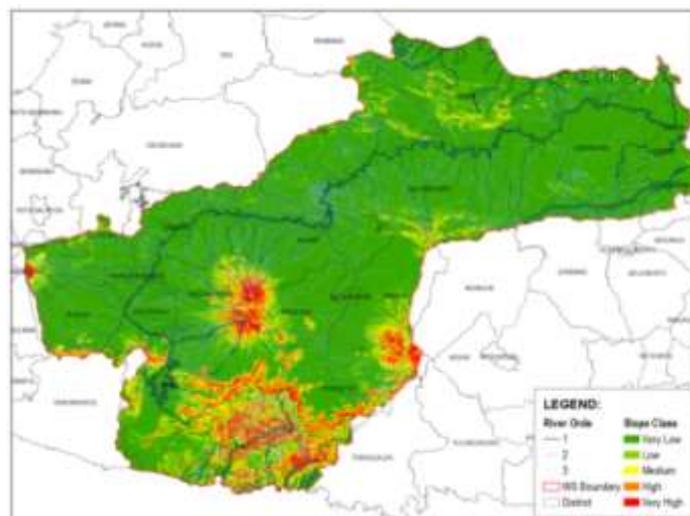


Figure 6. Results of slope assessment in Bengawan Solo river basin

4.5. Overlay process between variables

The overlay process is the mapping process of each variable determining the recharge area to generate a recharge area map. Classification/ranking of recharge area is derived from the sum of the multiplicative multiplication (B) with the variable class (K), with the following formulation:

$$K_{DRA} = (K_S \cdot B_S) + (K_T \cdot B_T) + (K_H \cdot B_H) + (K_G \cdot B_G)$$

where:

- K_S : Class/Ranking value of the slope variable
- K_T : Class/Ranking variable type of soil type
- K_H : Class Value/Rainfall variable rating
- K_G : Class/Ranking value of geological condition variables
- B : Weight influences variables

The highest value of the overlay on the raking recharge area is 5 and the lowest is 1, the same as the class of each variable. A value of 1 is a value that the area is not good for water absorption, and a value of 5 indicates that the area is a very good water catchment area. Figure 7 shows final result class overlay between recharge area variables.

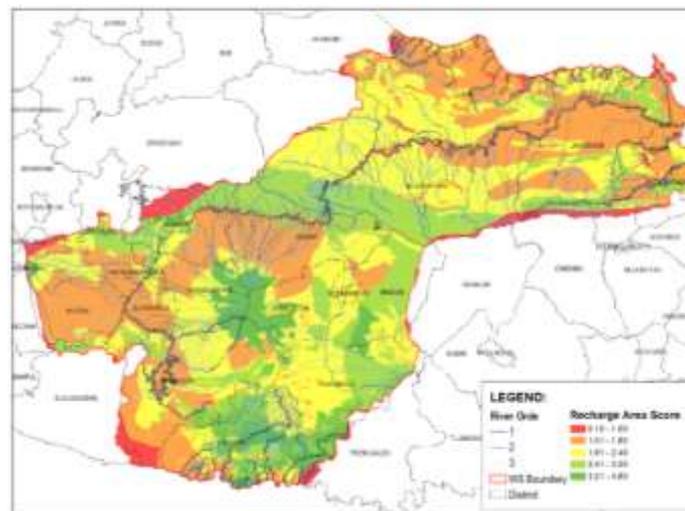


Figure 7. Results of a variable recharge area overlay

5. Conclusion and Recommendations

5.1. Conclusion

1. The results of the study show that the main variables for determining recharge areas are geological conditions, surface soil type, rainfall, and slope conditions. Each variable has a different influence proportions, depending on the condition of the region but the dominant factor is the geological condition. In the case of Bengawan Solo river basin, the proportion of each variable was: geology (40%), surface soil type (30%), rainfall (20%), and slope (10%). The class range of each variable can vary depending on the condition of the study area;
2. Using the overlay method in GIS, we can identify recharge areas. There are 532,475.01 hectares which can be used as a recharge area in the Bengawan Solo river basin, consisting of 387,069.29 Hectares of Priority I and 145,405.72 Priorities II. The total recharge area is around 29.7% from outside the river area.
3. By identifying the recharge area, it can be concluded that the land which is the recharge area has the main characteristics such as:

- a. Having a general direction of groundwater flow vertically downward viewed from its geological structure.
- b. Water seeps into the ground until the ground water level (fills the aquifer).
- c. Areas of rock outcrops escape water that is not saturated with water.
- d. Hills or mountains
- e. The age of groundwater is relatively young.
- f. The area of the body and cone of the volcano.
- g. Karst areas that have cracks and dissolution holes.

5.2. Recommendations

Recommendations that can be proposed for further research are as follows:

1. There needs to be an in-depth study of determining the influence of variables in determining the recharge area;
2. There is also a need to study the sensitivity of the class/ranking in each variable;

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