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Application of Hydrogeological Mapping and Geospatial Analysis to Determine Recharge and Discharge Areas in Sumowono Groundwater Basin

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Abstract Sumowono groundwater basin is locating at Semarang Regency, Temanggung Regency, and some part in Kendal Regency. Increasing population growth in the Sumowono groundwater basin area is the cause of increasing water demand. This study aims to determine groundwater utility by the community, the value of each determinant parameters of the recharge area, and the distribution of recharge and discharge areas. The research methods were hydrogeological mapping and geospatial analysis, which includes combining several geological and hydrogeological parameters, namely hydraulic conductivity, precipitation, soil cover, slope, water table depth, and electrical conductivity (EC). Based on the result of the hydrogeological mapping, groundwater is mainly used for irrigation, fisheries, industry and domestic purposes. The soil covers consist of sandy clay and clay sand. The slope has a value of 0°-40°. Rainfall has a range 2,500-3,200 mm/year, depth of water table is up to 20 m below ground surface. The hydraulic conductivity values are 3.1 m/day (tuffaceous sandstone), and 270 m/day (volcanic breccia) with the EC values is 36-550 µS/cm. Based on the results of the geospatial analysis, the recharge area is spreading in the south and the east, while the discharge area is located in the northern part of the study area.

1. Introduction

The term of groundwater basin is based on [1]as an area which is bordered by the hydrogeological boundary, where all hydrogeological events such as the recharging, flowing and dischargingprocesses take place. One of the groundwater basin criteria is to have recharge areas and discharge areas in the groundwater system.Groundwater recharge areas (groundwater catchment areas) and groundwater release areas (groundwater discharge areas) are two very different aspects in the hydrological cycle. The recharge area is the place where the process of water moves vertically to the saturated zone calls an aquifer. While the discharge zone is an area to describe the movement from subsurface to surface[2]. These two areas have different management, where the groundwater recharge area needs to preserve groundwater that needs to be maintained and conserved, whereas the groundwater discharge area needs to control related to groundwater abstraction [3]. Thus, this research is at aiming to determine the recharge area and discharge area by combining hydrogeological mapping and spatial analysis approach. Several researchers stated and applied spatial analysis is a fundamental part of the Geographic Information System to determine the recharge area and discharge area and other specific topics [4]-[10].

Geographicallythe Sumowono Groundwater Basin is located between 9197102-9215728 mN and 396658-426897 mS by using the Universal Transverse Mercator (UTM) zone 49of the Southern Hemisphere.Sumowono groundwater basin is situated in Temanggung regency, Semarang regency, and some part in Kendal regency (Figure 1).

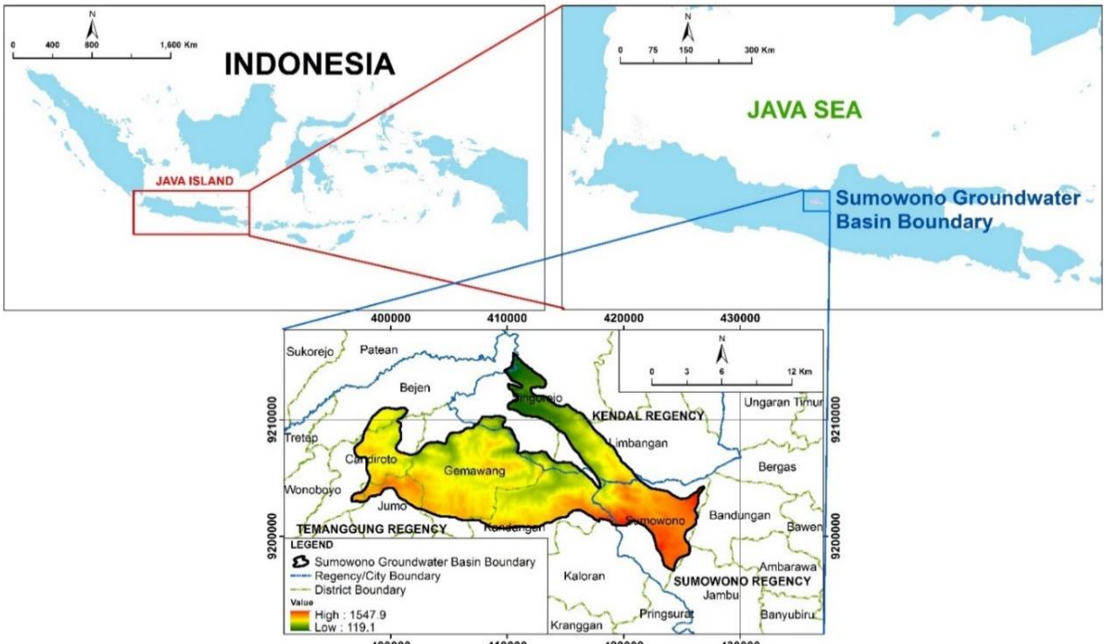


Figure 1. Study area. Sumowono groundwater basin is located in Semarang regency, Temanggng Regency, and Kendal Regency

Based on the regional geology of Magelang-Semarang sheet [11] as shown in Figure 2, the Sumowono groundwater basin consists of volcanic deposits, sedimentary rocks, and unconsolidated material. Andesite intrusion (TMA) is the oldest rock in the Sumowono groundwater basin, then followed by Basalt intrusion (TMB). Claystone, marl, and limestone as a part of sedimentary deposits from Kerek Formation (TMK). The volcanic products (Penyatan Formation/QTp; Kaligestas Formation/Qpkg; KemalonSangku volcanic rocks/Qpj; Jambanganvolcanic rocks/Qj; Gajahmungkur volcanic rocks/Qhg; Sindoro (Qsu) volcanic rocks and Sumbing lava deposit (Qsm) are represented by the presence of volcanic breccia, andesite lava, pyroclastic breccia, and tuffaceous sandstone. The youngest lithology is alluvial deposits (Qa) which consist of unconsolidated materials from gravel to clay.

Based on the regional hydrogeological maps (Figure 3), there are two types of aquifer systems, namely aquifer with flow through cracks, fractures, and channels and aquifer which low in productivity and without groundwater abstraction. The first aquifer is located in the south of Sumowono groundwater basin, which can be divided into a medium productive aquifer and local productive aquifer. This aquifer mainly consists of volcanic products while the rest is located mostly in the north and consists of sedimentary rocks and andesite and basalt intrusive rocks.

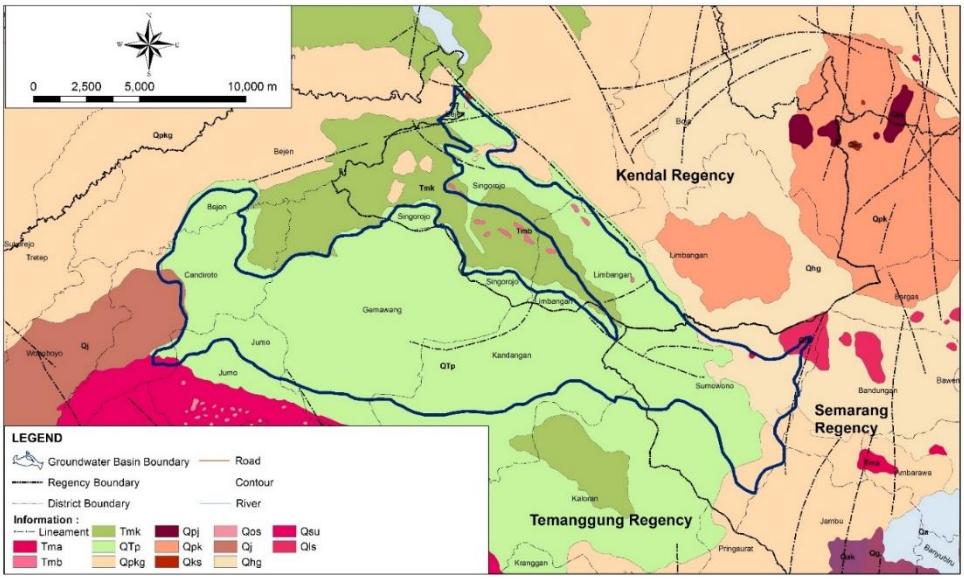


Figure 2. Regional geological map of Sumowono groundwater basin. Lithology consists of intrusive rocks, volcanic products, and alluvial deposits.

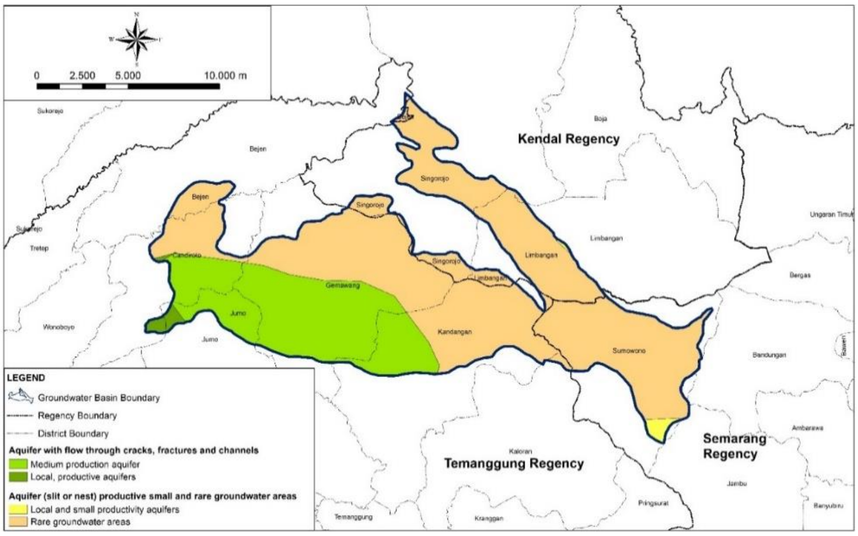


Figure 3. Regional hydrogeological map of Sumowono groundwater basin.

2. Methodology

Hydrogeological mapping conducted 115 measurements of dug wells and springs in the study area. Groundwater is mainly used for domestic purposes (Figure 4). Moreover, in the hydrogeological mapping, WtW Cond 3310 and WtW pH 3210 tools were applied to measure the electrical conductivity values. The geospatial analysis was employed by some researchers using geological and hydrogeological factors which wereanalysed in the Geographic Information Systemto determine the recharge and discharge zones[12]-[19]. There were six factorswhich can be applied,namely electrical conductivity, hydraulic conductivity, rainfall, soil cover, slopes, and groundwater depth. Every parameter has its class and weight, as shown in table 1. The geospatial analysis referred to statistical analysis based on factors and underlying processes. Finally, the groundwater recharge zone was generated by superimposing the factors above following their weight and classes.

Table 1. Factors for determining recharge zone and discharge zones

Factor	Weight	Class
Electrical Conductivity (µS/cm)	10	
a. 0-200		1
b. >200		0
Hydraulic Conductivity (m/d)	5	
$> 10^3$		5
10^1-10^3		4
10^{-2}-10^1		3
10^{-4}-10^{-2}		2
$< 10^{-4}$		1
Rainfall (mm/yr)	4	
> 4,000		5
3,000-4,000		4
2,000-3,000		3
1,000-2,000		2
< 1,000		1
Soil Cover	3	
Gravel		5
Pebble sand		4
Sandy clay/Sandy silt		3
Clayey silt		2
Silty clay		1
Slope (º)	2	
>40		5
20-40		4
10-20		3
5-10		2
<5		1
Groundwater depth (m)	1	
> 30		5
20-30		4
10-20		3
5-10		2
<5		1

3. Results and Discussion

3.1 Hydrogeological mapping

Sumowono groundwater basin is located in the undulating plain areas to the steep hills with the altitude from 109 to 1,026 m above sea level. There are 115 measurements at the hydrogeological interest points (Figure 4a) which consists of springs and dug wells.The appearance of springs in the Sumowono CAT is abundantly found. Almost every village has a spring that comes out withdiverse discharge. The spring contained in the Sumowono CAT generally appearsin the sloping bend area or undulating plain area. The land uses of Sumowono groundwater basin are dominated by plantation/garden, paddy field and scrub, as shown in Figure 4b.

The abundant springs are widely used for domestic and irrigation purposes. Moreover, springsare also utilized for industrial and fishery purposes in some specific areas, as depicted in Figure 5a. The existence of the abundant groundwater source from springs and dug wells is also supported by the excellent quality of groundwater measured which is shown from the results of physical water quality measurements such as pH and Electrical Conductivity/EC values (Figure 5b). The pH has a range from 6.21-7.98. The range is allowed in the water drinking standard as mentioned in Permenkes No. 492/2010 while the EC value starts from 36 to 550 µS/cm. The EC range shows excellent groundwater quality based on classification from [20]. The EC value is the weight parameter to determine the recharge area.

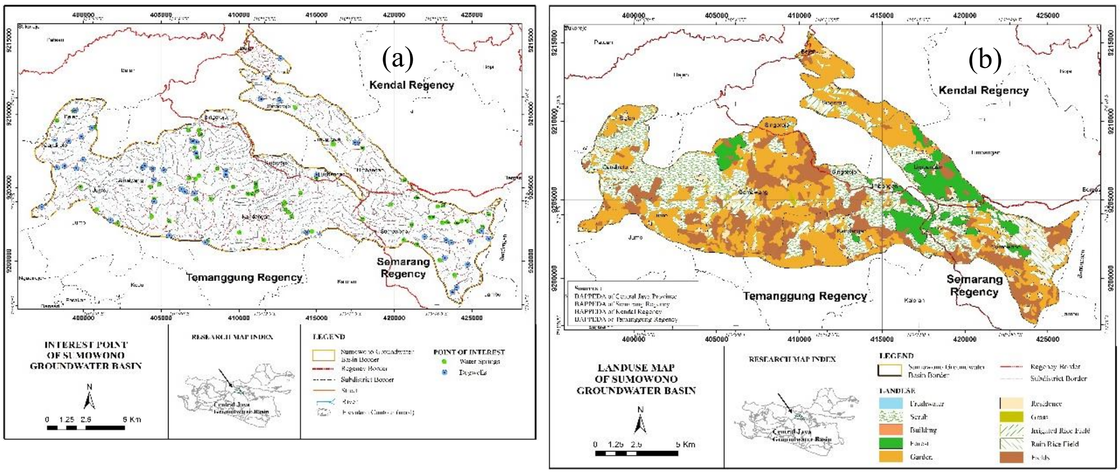


Figure 4. The distribution of hydrogeological interest points (a) and land use in the study area (b).

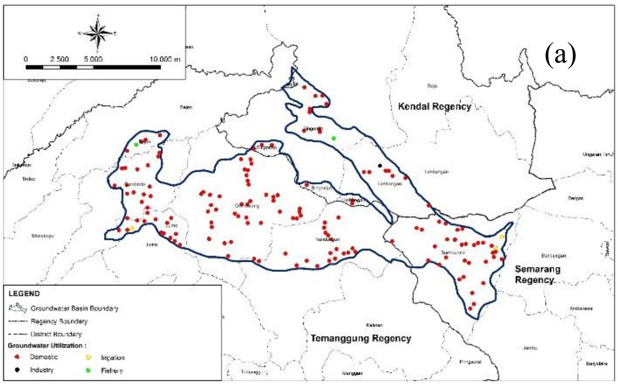
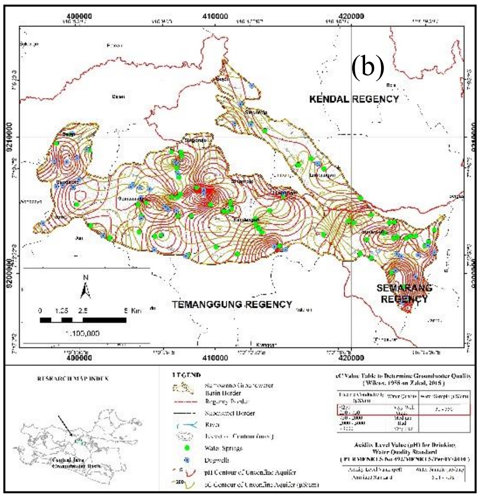


Figure 5. Groundwater used map (a) and its physical quality parameters (b)



3.2 Geospatial analysis

To Determine the recharge and discharge areas, so several parameters are applied as geological and hydrogeological parametersreferenced from [3]. The parameters are hydraulic conductivity, rainfall, soil cover, slope, and groundwater depth. Moreover, the groundwater quality from the EC value is addedtothe calculated parameter in the spatial analysis. The EC is an essential indicator of water quality assessment. Since the composition of mineral salts influence the electrical conductivity of groundwater, it is crucial to understand the relationships between mineral saltcomposition and electrical conductivity[21]. The weight and classes for each parameter are shown in Table 1 above.

Based on the hydrogeological mapping, the EC values in the study area can be classified into two groups, i.e. from 37-200 μS/cm and 200-537 μS/cm, which is pictured in Figure 5a. The first group has value one while the other has 0, then the values are multiplied by the weight (10). The total value of the EC value has a range of 0-10.

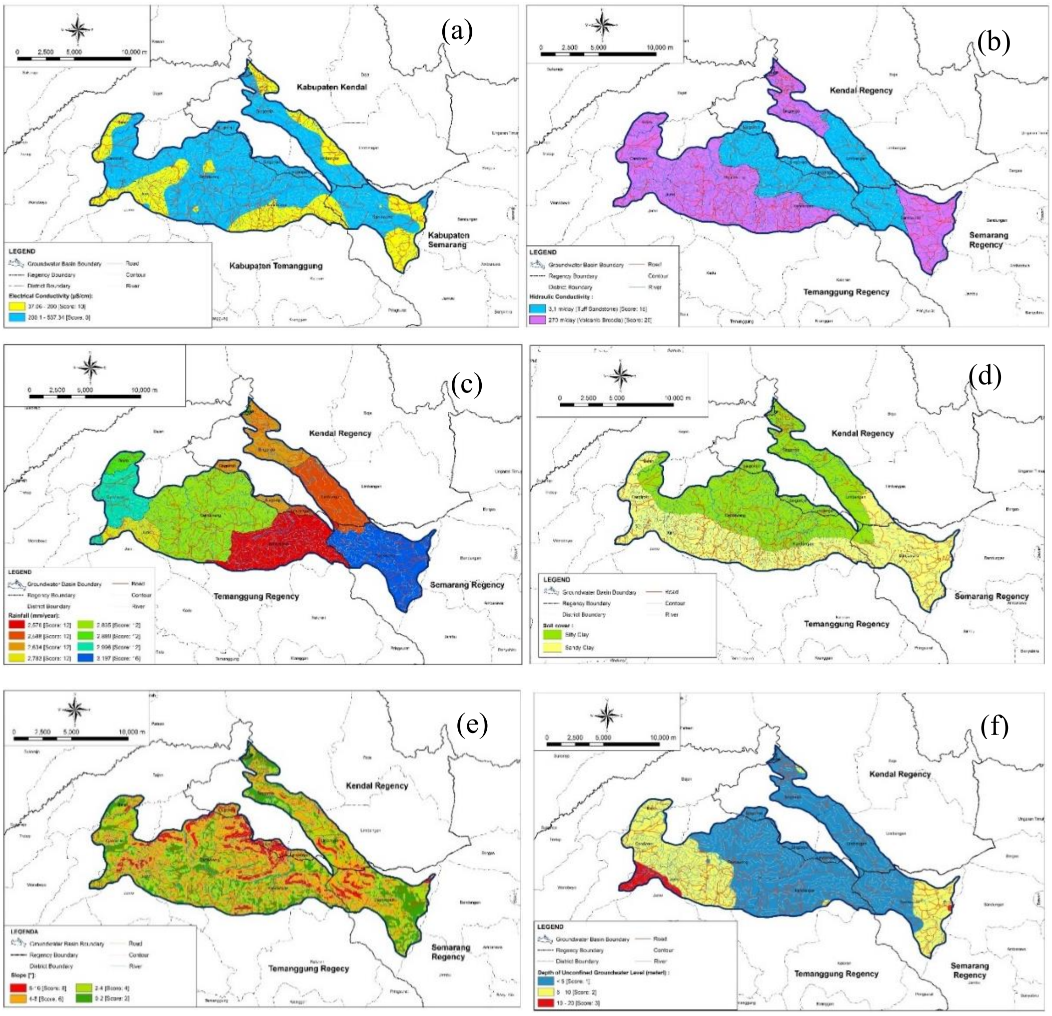


Figure 6. Parameters influence for determining the recharge and discharge areas. Electrical conductivity (a); hydraulic conductivity (b); rainfall (c); soil cover (d); Slope (e); Groundwater depth (f)

The second parameter is hydraulic conductivity (K). Hydraulic conductivity of the material related to the ability of the fluid to pass through the pores and fractured rocks. The conductivity depends on the type of lithology that is found in the areas [21]. Lithology in the study area consists of tuff sandstone and volcanic breccia. Tuff sandstone is located in the center and the north of the study area while in the south, the west, the east, and some part in the north is composed of volcanic breccia. [22] stated that tuff sandstone and volcanic breccia have the values of hydraulic conductivity are 3.1 m/day and 270 m/day, as shown in Figure 6b. The K values have class 3 and 4, and with the weight of 5, so the total scores are 15 and 20.

Rainfall is a climate parameter which affected the groundwater recharge. High rainfall will have the possibility of water to flow vertically into saturated zone. In the study area rainfall has a range of 2,500-3,200 mm/yr. The distribution of rainfall is shown in Figure 6c. The study area has two classes

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of rain which are 2,000-3,000 mm/yr (Class 3) and 3,000-4,000 mm/yr (Class 4). With the weight of rainfall is 4, the total scores of rains are 12 and 16 as shown in Figure 6c.

Soil cover is one of the parameters which affects water to infiltrate into the saturated zone. In the study area, sandy clay and silty clay are the compositions of soil cover, as shown in Figure 6d. Sandy clay is mainly located in the south while silty clay spreads in the north. The classes are on3 and 1 respectively. The weight of soil cover is 3, thus the total scores are 9 and 3 for the sandy clay and silty clay, respectively.

The slope is fundamental in identifying the groundwater recharge zones due to it impacts the runoff as well as infiltration rate. Generally, gentle to steep slopes are prospects of high groundwater potential, more rainfall can percolate into the subsurface. In the study area, the range of slope is 0-16^{o}. The slope can be divided into four classes, as shown in Figure 6e. With the weight of 2, the scores of slopes are 2-8.

Depth of groundwater level is the distance between the ground surface and water table. The deeper groundwater level in an area shows that the area can absorb water significantly and characterize as groundwater recharge areas. Conversely, the shallower groundwater level in an area indicates that the area is not able to absorb water properly and identified as a discharge area. Groundwater depth in the study area can be grouped into three classes with the weight is 1. Groundwater level below 5 m has total value 1, while 5-10 m depth is 2, and the rest (10-20 m depth) is 3. The lowest depth of water table is dominantly in the centre to the north while the deepest is in the south-west.

The recharge and discharge zones are developed by overlaying the determinant groundwater contributing thematic layers (Figure 7). The recharge and discharge zones are evaluated based on the total scores of 6 parameters which are computed from the integration of all geological and hydrogeological influencing thematic maps using spatial analysis approach. The overall scores have a range of 33-62. Thus, the area of recharge zone has a range from 42 to 62 while 33-62 is identified as a discharge zone, as shown in Figure 7. The recharge zone is located in the south with the land use dominated by plantation, paddy field, and scrubs in the hilly areas.

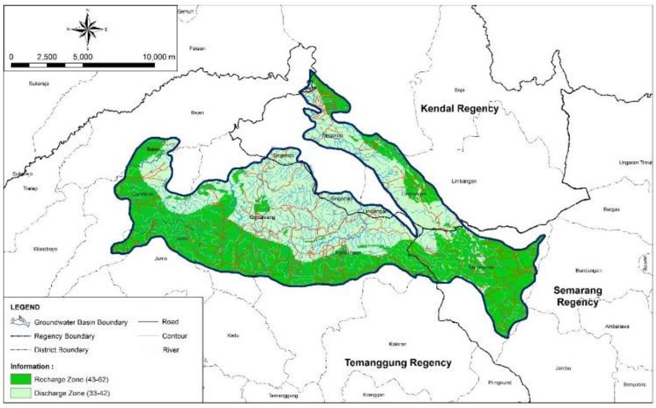

Figure 7. The recharge zone of Sumowono groundwater basin.

4. Conclusions

Groundwater is a vital resource for sustainable growth of the country with sustainable management of water resources. Hydrogeological mapping and geospatial analysis have integrated for evaluating recharge and discharge zones of the study area using the different thematic maps such as like electrical conductivity, hydraulic conductivity, rainfall, soil cover, slope, and groundwater depth. The weight of thematic parameters was assigned based on their characteristic for groundwater contribution and wasoverlaid and integrated for determining the recharge and discharge zones. This study is fundamental for sustainable use of groundwater resources for developing activities and its protection for natural resources. The results show that the recharge area is located in the south of the study area.

Further studiescan be developed on the groundwater hydro-chemistry and its suitability for domestic and irrigation as well as evaluating the conservation zone.

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