IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Application of Spatial Analysis for Delineating Groundwater Recharge Zone for Industrial Usage in Tanah Bumbu Regency, South Borneo/Indonesia

To cite this article: T T Putranto and S Purba 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **598** 012093

IOP Conf. Series: Materials Science and Engineering **598** (2019) 012093 doi:10.1088/1757-899X/598/1/012093

Application of Spatial Analysis for Delineating Groundwater Recharge Zone for Industrial Usage in Tanah Bumbu Regency, South Borneo/Indonesia

T T Putranto[1] and S Purba[1]

[1]Geological Engineering Department, Faculty of Engineering, Diponegoro University, Jl Prof. Soedharto SH, Tembalang Semarang 50275 Indonesia

putranto@ft.undip.ac.id

Abstract. Population growth in Tanah Bumbu Regency South Borneo Province is causing increased water demand. To fulfil the water needs, the government provides an alternative water resource by using groundwater as a source of fresh water. The objective of this research is to delineate the groundwater recharge zone. The methods were hydrogeological mapping and spatial analysis approach to delineate the groundwater recharge zone. There were six parameters applied in the research, i.e. hydraulic conductivity, rainfall, slope, soil cover, water table depth, and electrical conductivity. The varies of hydraulic conductivity are 45 m/day (sandstone), 0.94 m/day (limestone), 0.49 m/day (alluvium) and 0.2 m/day (serpentinite). Rainfall has a range from 2,106 to 2,403 mm/year. There are several types of soil cover which are gravel, sand pebbles and clay sandstones. The slopes are varying from below 5° to 40°. The groundwater depth is varying from below 5 m to 10 m depth. Furthermore, the electrical conductivity of groundwater samples has a value around 14.9-1,477 µS/cm. Overlying all parameters in spatial analysis resulted in the recharge area spread in the north, centre, and northwest of the study area.

1. Introduction

Groundwater as one part of water resources is the most desirable resource for humans. The presence of groundwater is very abundant, and good quality is one of the factors of high human interest in making groundwater one of the sources of clean water [1]. As the most popular water source, it needs to be done carefully to carry out groundwater management and utilization.

Groundwater is a portion of the earth's surface water circulation system known as the hydrological cycle. Practically groundwater comes from surface water. The main source of recharge is precipitation, river flow, lakes, and reservoirs or reservoirs. Other known contributions such as artificial recharge, access to irrigation, seepage from channels, and water are deliberately applied to increase groundwater supplies [2].

Groundwater Basin based on [3] stated as an area which is limited by hydrogeological boundaries, where all hydrogeological events such as the process of filling, flowing and releasing groundwater take place. One of the groundwater basin criteria is to have recharge areas and groundwater release areas in a groundwater formation system.

Groundwater recharge areas and groundwater discharge areas are two very different aspects of the hydrological cycle. Groundwater recharge areas are involved in the entry of groundwater into aquifers, while groundwater release areas are involved in groundwater discharge activities [4]. These two zones have different management, where groundwater recharge areas need to be maintained and preserved their existence and condition, whereas groundwater release areas that function as natural groundwater output areas on groundwater basin need to be controlled in taking groundwater. The two regions have different ways of managing, so it is necessary to know the location of recharge areas and release of groundwater such as in a groundwater basin [5]. Pagatan groundwater basin which is located in Tanah Bumbu Regency, South Borneo has a role in providing groundwater for residents, such as springs and dug well. In line with the growth and development of the region in Tanah Bumbu regency and given the importance of maintaining regional balance, a study is needed on determining the recharge area and discharge areas, to have appropriate treatment for each area. Information about the location of recharge areas is also beneficial to assess the licensing of drilling wells so that the drilling wells in the recharge areas should be avoided. Many assessments of spatial analysis using Geographic Information System/GIS have been reported [6-11]. Thematic maps such as geology, land use, rainfall, soil cover, slope, and water table depth are integrated by various features derived from field campaign and secondary data [12-16]

2. Geologic setting

Pagatan groundwater basin in Tanah Bumbu Regency is located between 9660134-9576345 m (North) and 315323-398713 m (East) in the Universal Transverse Mercator coordinate system (Figure 1). The Regency of Tanah Bumbu is stratigraphically included in the Barito Basin. The Barito Basin is a delta coal deposition environment. According to [17], in the beginning, the Barito Basin and the Acid-Acid Basin were the same basins, but the removal of the Meratus Mountains in the Early Miocene period caused the basin to separate into two basins. The area of Pagatan groundwater, where Tanah Bumbu Regency is located, is included in the Banjarmasin Geological Map Sheet [18]. The geological formations found in the study area from the oldest to the young (Figure 2), namely:

a. Ultramafic (Mub) Formation consists of serpentinite, gabbro, basalt, harzburgite, durite, and concentrated pyridine.
b. Tanjung Formation (Tet) consists of conglomerate, sandstone and claystone intersections with shale inserts, coal and limestone.
c. Berai (Tomb) Formation consists of bioclastic limestones, locally intersected with marl and sandstone, containing nodules. The unit thickness is between 500-1500 m.
d. Warukin Formation (Tmw) consists of alternating quartz sandstones and claystone, with shale, coal and limestone inserts deposited in the litoral-paralysis environment with a thickness of 250-750 m.
e. Dahor Formation consists of quartz sandstones, fragile, locally insulated with clay, lignite, limonite, smoke quartz and basalt. This formation is deposited in the parental environment, and the thickness of the unit is around 750 m.
f. Alluvium (Qa), occupying coastal plains, rivers and swamps. Formed by sedimentary mechanisms, both land and sea, which come from sediments of rivers, swamps, and beaches.

3. Methods

Determination of recharge and discharge zones was carried out by geological and hydrogeological field campaign and secondary data such as precipitation and hydraulic conductivity. Geological surface mapping and geomorphological observation, water table measurement, and collection of groundwater samples via dug wells were the activities in the field campaign. There were 156 water table measurements which are located in 10 sub-districts in the research area. Observation of geological conditions was achieved by investigating the distribution of lithology, geological processes and hydrogeological boundary. The parameter values of electrical conductivity, water table depth, hydraulic conductivity, rainfall, soil cover, and slope were analyzed by weighting and rating in spatial analysis using GIS to determine the groundwater recharge zone. Table 1 to Table 6 as follows [5] were applied in the spatial analysis approach. The weight of a parameter represents the proportion of its value in the potential recharge scale. Thus, the higher the recharge weigh parameter, the larger the importance of parameter was. Moreover, the electrical conductivity value was applied to support the assessment for determining the recharge zone as shown in table 7. Recharge potential zone (P_r) can be express as:

$$P_r = \sum wi.ri \quad (1)$$

where wi is the ith factor weight [-]; ri is the ith rating value [-], and the i refer to the individual features of a parameter.

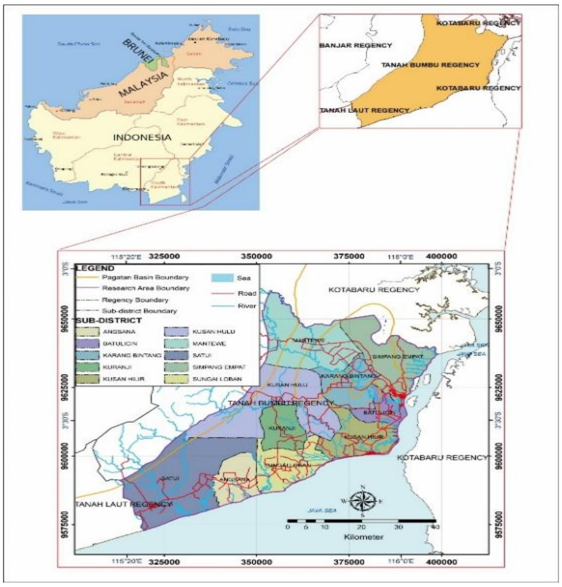

Figure 1. Study area, Tanah Bumbu Regency in Pagatan groundwater basin

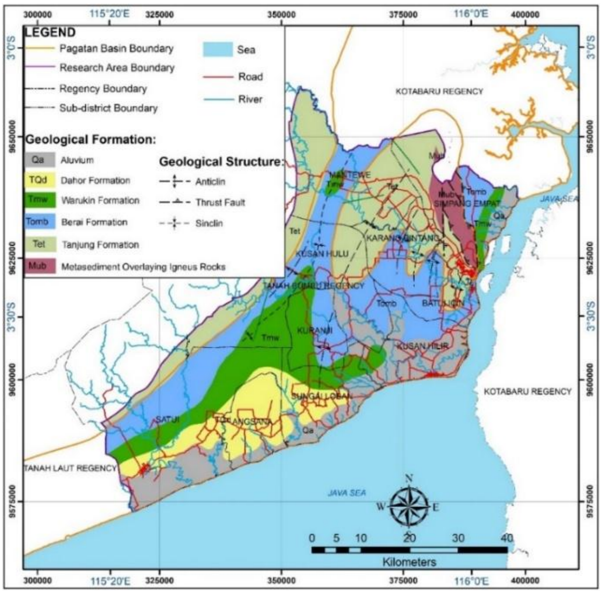

Figure 2. Regional geological map of Tanah Bumbu Regency.

Table 1. Weighted scale for determining groundwater recharge zone.

No.	Parameter	Weight	Description
1	Hydraulic Conductivity	5	Extreme importance
2.	Rainfall	4	Fairly importance
3.	Electrical Conductivity	3	Importance
4.	Soil Cover	3	Importance
5.	Slope	2	Low importance
6.	Water table depth	1	Very low importance

Table 2. Hydraulic Conductivity level

No.	Hydraulic conductivity (m/day)	Rating Value	
1.	$> 10^{3}$	5	Very high
2.	10^{1} - 10^{3}	4	High
3.	10^{-2} - 10^{1}	3	Moderate
4.	10^{-4} – 10^{-2}	2	Low
5.	$< 10^{-4}$	1	Very Low

Table 3. Rainfall

No.	Rainfall (mm/year)	Rating Value	
1.	> 4,000	5	Very high
2.	3,000-4,000	4	High
3.	2,000-3,000	3	Moderate
4.	1,000-2,000	2	Low
5.	< 1,000	1	Very Low

Table 4. Soil cover

No.	Soil cover	Rating Value	
1.	Gravel	5	Very high
2.	Gravelly sand	4	High
3.	Sandy clay	3	Moderate
4.	Clayey silt	2	Low
5.	Silty clay	1	Very Low

Table 5. Slope level

No.	Slope (°)	Rating Value	
1.	>40	5	Very high
2.	20-40	4	High
3.	10-20	3	Moderate
4.	5-10	2	Low
5.	<5	1	Very Low

Table 6. Water table depth

No.	Water table depth (m)	Rating Value	
1.	> 30	5	Very high
2.	20-30	4	High
3.	10-20	3	Moderate
4.	5-10	2	Low
5.	<5	1	Very Low

Table 7 Electrical Conductivity range

No.	Electrical Conductivity (μS/cm)	Rating Value	
1.	< 250	5	Very high
2.	250 - 750	4	High
3.	> 750	3	Moderate

4. Results and Discussion

Details of thematic maps relevant for delineating the recharge and discharge zones are given in the following.

4.1. Hydraulic conductivity map

The hydraulic conductivity is a parameter with the highest weight value that is worth 5 (Table 1). The hydraulic conductivity measures the ease water moved through the subsurface and applied to calculate rates of water movement.

Based on the geological surface mapping, the study area can be divided into four lithological units, namely areas with alluvium dominance, sandstone, limestone, and serpentinite as seen in Figure 3a. According to [18], the hydraulic conductivity of the alluvium region is 0.49 m/day. Alluvium in the study area are classified as soil containing a lot of sandy material. This area is located in the east and southeast of the research area, nearby the coast, namely in the District of Simpang Empat, Batulicin District, Kusan Hilir District, Loban River District, and Angsana District. Furthermore, serpentinite has a rock conductivity value of 0.2 m/day. This lithology is a concentrated ultramafic rock and spread in Simpang Empat District. While limestone which is classified as medium sand has a rock conductivity value of 0.94 m/day. These limestones are classified as medium sand size. This lithology spreads in the border of the research area in the northwest and the north, namely in Satui District, Kusan Hulu Subdistrict, Mentewe District, Simpang Empat District and, Batulicin District. While sandstone with a rough size has the hydraulic conductivity is 45 m/day. This lithology is distributed in the centre, precisely in the Kuranji District, Angsana District, Satui District, Kusan Hulu District, Mentewe District,

IOP Conf. Series: Materials Science and Engineering **598** (2019) 012093 doi:10.1088/1757-899X/598/1/012093

Simpang Empat District and Kusan Hilir District. Based on table 2, the rating values of hydraulic conductivity of alluvium, limestone, and serpentinite are 3 while 4 is allocated for sandstone. With the weight of 5, the total score of hydraulic conductivity is the range 15-20.

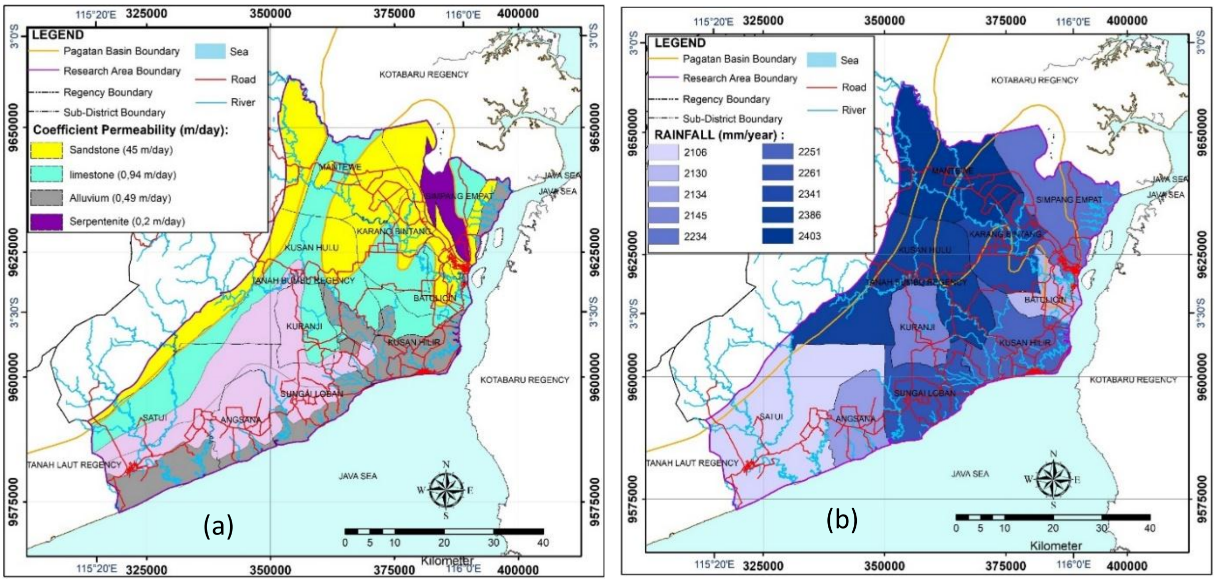

Figure 3. Hydraulic conductivity map (a) and rainfall map (b)

4.2. Rainfall

Rainfall will affect the amount of water that enters the soil, with high rainfall the water absorption will be even greater if the rain occurs in a long period. The higher and longer the rainfall, the greater the value because it shows the amount of water supply that can infiltrate into the soil or rocks that fill the aquifer layer in a groundwater basin system.

The research area has rainfall 2,106-2,403 mm/year [19]. The areas with the highest rainfall are Mentewe sub-district and Kusan Hulu sub-district. Based on table 3, the delineation rainfall parameter has only one class, namely at an average of 2,000-3,000 mm/year which is included in the third rank. With a weight of 4, the total score of rainfall is 12. The rainfall map can be seen in Figure 3b.

4.3. Soil Cover

This parameter is influenced by the permeability properties of the soil based on the condition of soil grains which are more likely from sand to clay. This parameter is very influential on the ability of leach from the surface to infiltrate water into the soil because, with the impermeable surface layer of the soil, it will result in the difficulty of water entering the soil. The distribution of soil cover types in the study area can be seen in Figure 4a. Based on the data obtained from the field campaign, the type of soil cover can be divided into three namely sandy clay, gravely sand, and gravel.

Areas that consist of gravel are given a rating of 5. These areas spread in Kusan Hulu, Mentewe, Satui and Simpang Empat sub-districts. Areas that soil covers are gravely sand have a rating of 4 (table 4). These areas are located in Satui sub-district, Kusan Hulu sub-district, and Satui sub-district. Meanwhile, the areas with soil cover are sandy clay have a rating of 3 and spread in Kuranji sub-district, Angsana sub-district, Loban River sub-district, some part in Kusan Hilir sub-district and Satui sub-district. With the weight of 3, the total score of soil cover has a range from 9-15.

4.4. Slope

The slope of an area will greatly affect the process of water infiltration. The greater the degree of slope, the easier the amount of water that infiltrates into the soil. This research area has varying slope values (Figure 4b).

Variations in the degree of slope in this study area can be classified into 4 regions following table 5. The areas which have slope values of <5° and 5°-10° which spread throughout the research areas have ratings of 1 and 2, respectively. Meanwhile areas with a slope of 10°-20° have a rating of 3 is located in Simpang Empat sub-district, Mentewe sub-district and some part in Kusan Hulu sub-district. While the areas with a slope of 20°-40° with a rating of 4 spread in Simpang Empat sub-district and Mentewe sub-districts. With the weight of 2, the total score of the slope has a value from 2 to 8.

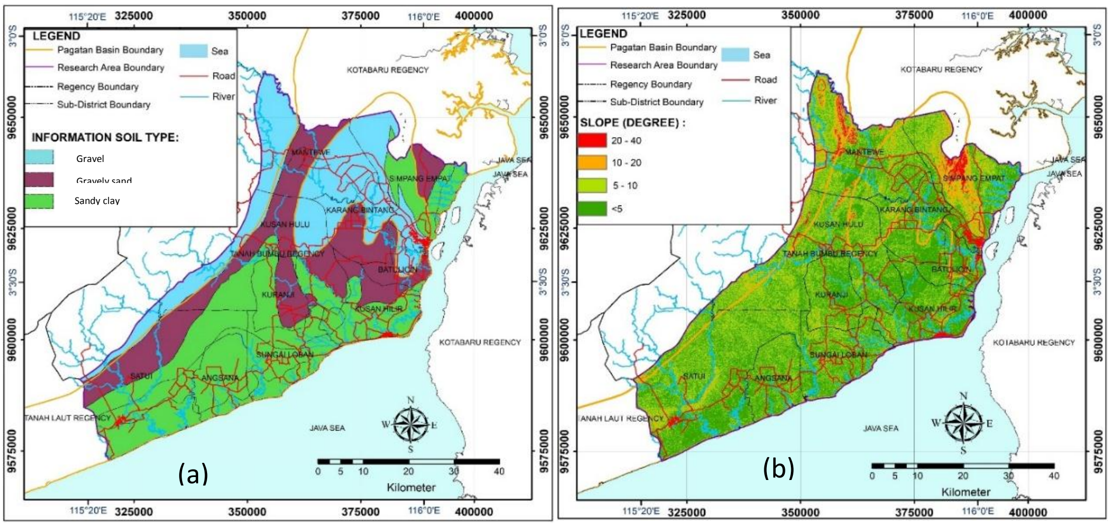

Figure 4. Soil cover map (a) and slope map (b)

4.5. *Water table depth*

Water table depth is the distance between the ground surface to groundwater. The deeper the water table indicates that the area can infiltrate water properly and show the characteristics of groundwater recharge areas. Water table depth is the smallest weight with a value of one. The value of one indicates that this parameter is less influential in determining the groundwater recharge zone.

The research area can be divided into two zones based on the water table depth as following table 6. Areas with water table depth less than 5 m have the rating 1 which are located in Batulicin sub-district, Kusan Hilir sub-district, Angsana sub-district, Sungai Loban sub-district, and Kusan Hilir sub-district as shown in Figure 4b. Meanwhile, areas, where the water table depth is around 5-10 m depth, have a rating two (2). These areas are located in some part of Batulicin sub-district, Mentewe sub-district, Simpang Empat sub-district, Kuranji sub-district, Kusan Hulu sub-district, Satui sub-district, and Kusan Hulu sub-district. With a weight of 1, the total score of water depth is around 1-5.

4.6. *Electrical conductivity (EC)*

Electrical conductivity is a fundamental parameter for water quality assessment. Considering the composition of mineral salts influence the electrical conductivity of groundwater, it is essential to comprehend the linkage between mineral salt composition and electrical conductivity. Conductivity is the first indicator of change in a water system. Major change due to geogenic or anthropogenic factors can be very harmful to water quality.

Based on the measurement of EC values from 156 groundwater samples (dug wells), the study area can be divided into three classes (Figure 5b) as following table 7. Areas that have EC values less than 250 µS/cm, a rating of 5 based on table 7, are located in Satui sub-district, Loban River sub-district, Mentewe sub-district, Kusan Hilir sub-district, Karang Bintang sub-district, Kusan Hulu sub-district, and Kuranji sub-district. Meanwhile, areas with EC values of 250-750 µS /cm, a rating of 4, are located in Kusan Hilir sub-district, Simpang Empat sub-district, and Batulicin sub-district. Furthermore, regions with EC value of more than 750 µS/cm which has a rating of 3 spread in Angsana sub-district, Satui sub-district, and Batulicin sub-district. With the weight of EC parameter is 3, the total score of EC is around 9-15.

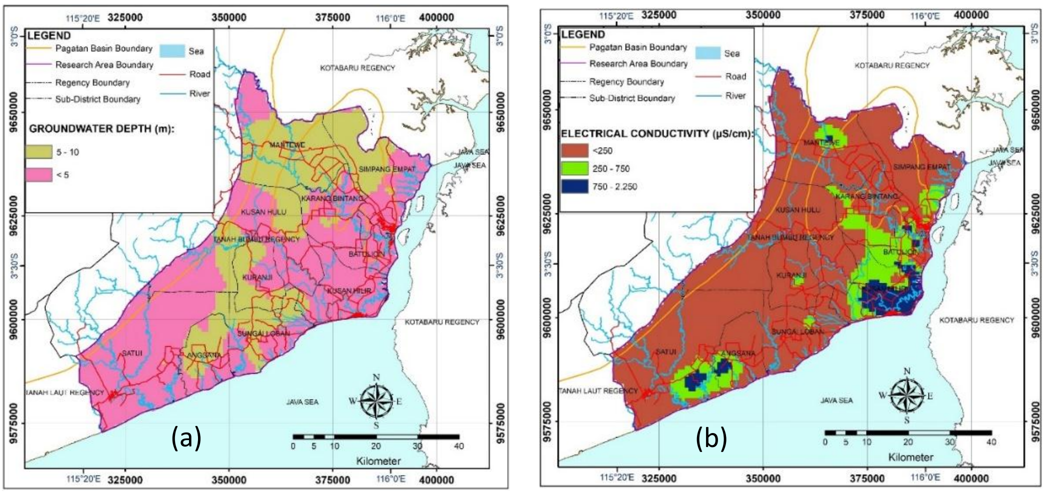

Figure 5. Groundwater depth map (a) and electrical conductivity map (b)

4.7. Delineating the groundwater recharge zone

Based on the results of overlying parameters of hydraulic conductivity, rainfall, soil cover, slope, water table depth, and electrical conductivity, the values obtained can be used as a reference in classifying recharge zones and discharge zones. Following equation 1 the resulting values, 33-68, are reclassified into two zones, namely, recharge zone and discharge zone as depicted in Figure 6. Discharge zone has a range 33-48 while recharge zone is from 49 to 68.

The recharge area is located in the northwest of Mentewe sub-district, Kusan Hulu sub-district, Simpang Empat sub-district, in the north of Karang Bintang sub-district, in the northern part of Angsana sub-district, Loban River sub-district in the North, and Satui sub-district in the centre. Geomorphological unit of the recharge zone is hilly with steep hilly terrain which the slope is around 20°-40°. Recharge zone area consists of lithology which has excellent porosity and hydraulic conductivity, namely coarse grains and sandstones which tend to be easy to transmit water into the ground. Furthermore, the recharge area has an EC value below 250 µS/cm which is indicating excellent groundwater quality in this zone.

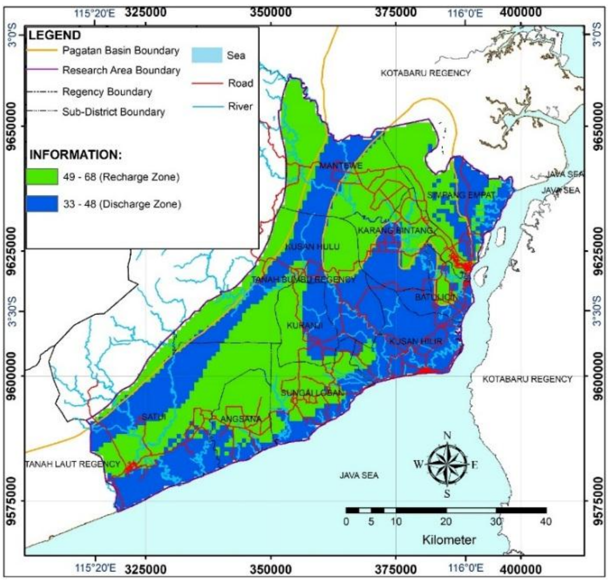

Figure 6. Groundwater recharge zone

5. Conclusion

In this study, an integrated approach for delineating the groundwater recharge zone using spatial analysis in GIS was proposed in Tanah Bumbu Regency which is located in the Pagatan groundwater basin. This study conducts the groundwater recharge zone map which is fundamental for the government to protect the recharge area and provide permission new deep wells in the discharge area. Protecting recharge area from human activities will provide significant values in the groundwater management and avoid environmental problems such as lowering the water table, groundwater pollution, seawater intrusion, etc. occur. The groundwater recharge zone spread in the north, in the centre, and the northwest of the study area. Groundwater recharge zone is located mainly in sandstone and limestone which has excellent porosity and hydraulic conductivity. The morphology is hilly with steep hilly terrain which has slope is around 20°-40°, and the EC value is below 250μS/cm. Details analysis of hydrogeochemical analysis, as well as aquifer geometry using pumping test, are needed to develop groundwater used for community and quantify groundwater need for industrial usage in the discharge area.

6. Acknowledgement

The authors are extremely thankful to the Energy and Mineral Resources Agency in South Kalimantan for extremely cooperation in the field campaign and to the Engineering Faculty in the Diponegoro University who funded the research with the scheme Strategic Research in 2019.

7. References

[1] Yudistira A and Adji T N 2013 J. Bumi Indonesia **2** 104-12
[2] Todd DK and Mays LW 2005 *Groundwater Hydrology 3rd Edition* (John Wiley & Sons, New York)
[3] Kementerian Energi dan Sumber Daya Mineral 2017 *Permen ESDM No 2 Tahun 2017 tentang Cekungan Air Tanah* (Jakarta)
[4] Rose S 2009 Groundwater recharge and discharge (UNESCO-EOLSS) **3**
[5] Danaryanto T H, Setiadi H and Siagain Y 2004 *Kumpulan Pedoman Teknis Pengelolaan Air Tanah* (Badan Geologi Bandung)
[6] Chenini I, Mammou A B and May M E 2010 *J. Water. Resources. Management.* **24** 1-19
[7] Al-Qudah K and Abu-Jaber N 2009 *J. Water. Resources. Management.* **23** 603-15
[8] Baker M E, Wiley M J and Seelbach P W 2001 *J. Water. Resources. Management.* 37 1615-28
[9] Chowdary V M, Ramakrishnan D, Srivastava Y K, Chandran V and Jeyaram A 2009 *J. Water. Resources. Management.* **23** 1581-602
[10] Ghayoumian J, Mohseni Saravi M, Feiznia S, Nouri B and Malekian A 2007 *J. Asian. Earth. Sci.* **30** 364–74
[11] Jha M K, Chowdhury A, Chowdary V M and Peiffer S 2007 *J. Water. Resources. Management.* **21** 427–67
[12] Yeh H F, Cheng Y S, Lin H I and Lee C H 2016 *J. Sustainable. Environment. Research.* **26** 33-43
[13] Gupta M and Srivastava P K 2010 *J Water International* **35** 233-45
[14] Preeja K R, Joseph S, Thomas J and Vijith H 2011 *J. of the Indian Society of Remote Sensing* **39** 83-94
[15] Choi W, Galasinski U, Cho S J and Hwang C S 2012 J Geographical Analysis **44** 219-34
[16] Sener E, Davraz A and Ozcelik M 2005 *Hydrogeology Journal* **13** 826-34
[17] Satyana A and Silitonga P D 1994 *Proc Indonesian Petroleum Association* (Jakarta: IPA)
[18] Sikumbang and Heryanto 1994 *Geological map of Banjarmasin Sheet, South Kalimantan* (Pusat Penelitian dan Pengembangan Geologi Bandung)
[19] Badan Pusat Statistik Provinsi Kalimantan Selatan 2018 *Provinsi Kalimantan Selatan Dalam Angka 2018* (Banjarmasin)