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Regional Case Study

Determination of Sustainable Groundwater Conservation Zones Based on Groundwater Recharge Areas: Case Study: Denpasar City

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Abstract

Groundwater is a valuable resource for meeting the daily needs of humans, which continues to increase along with population growth. Therefore, it is essential to maintain groundwater properly. Groundwater management can be carried out comprehensively in groundwater basins, including determining groundwater recharge areas. This study aims to determine the location of groundwater recharge to conserve groundwater in Denpasar City to create groundwater sustainability. The geospatial analysis uses a weighting and scoring approach (Overlay Weighted Sum) to determine the groundwater recharge area. Retrieval data in the field by observing geological conditions and measuring the depth of the phreatic surface in Denpasar City. The determination of recharge and discharge areas was analyzed using the geospatial method using the ArcGIS 10.8 application using Interpolation Inverse Distance Weighted (IDW). The five parameters used in this scoring assessment are lithology, rainfall, soil cover type, slope, and phreatic surface depth. The highest score obtained from the weighting of the scoring is 46, while the lowest score is 36. The recharge area is found in the weighted value of 41-46, which is in the northern region of Denpasar City. The discharge area is located at a weight value of 36-41 in the southern area of Denpasar City.

***Keywords**: Groundwater; recharge area; discharge area; sustainability; ArcGis; overlay*

1. Introduction

Groundwater is a water resource stored underground or in an aquifer system. Groundwater is a very important source of water for people's daily lives. In addition to meeting basic human needs, groundwater is used for agriculture and industry. These various interests often result in conflicting water needs between the community and industry, so groundwater has several functions, namely as a social function (fulfilment of community needs), economic (industry) and environmental carrying capacity. The role of groundwater, which tends to increase, can be understood because of several advantages; namely, the quality of the water is generally good, the investment cost is relatively low, and its utilization can be done where it is needed (in situ) (Ardana et al., 2022).

The groundwater problem has become a serious problem and is of concern to all parties. As one of the main sources of clean water, groundwater will be increasingly utilized. If it is taken excessively, there will be an imbalance between the water entering the ground (recharge) and the groundwater taken (extraction). Changes in land use, especially catchment areas that have changed their function, have also occurred massively, which has caused an imbalance between the recharge and extraction processes which will threaten the sustainability of the groundwater itself. (Ardana et al., 2022). Because groundwater has become an important water resource supporting people's daily needs, groundwater needs to be managed properly.

Groundwater recharge is one of the main components in the groundwater system in the form of a downward flow of water towards the saturated zone, which causes an increase in the groundwater level or is the process of replenishing water into an aquifer layer in a groundwater basin (*Cekungan Air Tanah*). Identification of groundwater recharge areas is an important component in effective and sustainable groundwater management to prevent a significant decrease in water resources and maintain a groundwater system's sustainability. (Afrifa et al., 2017; Nimmo et al., 2005; Obuobie, 2008; Scanlon et al., 2002). The approaches used in identifying groundwater recharge areas still need to be determined. Hydrogeological data-based approaches that are usually used in identifying groundwater recharge areas are based on slope buckling, based on river flow patterns, based on the emergence of springs, based on the position of the groundwater table, and based on hydrochemical and isotopic approaches. (Peraturan Menteri Energi dan Sumber Daya Mineral Republik Indonesia Nomor 31, 2018). Several studies in determining the area of groundwater recharge have used a spatial approach based on the Geographic Information System (GIS) (Ahmed et al., 2021; Kaliraj et al., 2014; Senthilkumar et al., 2019) and combination with the weighting of classification parameters, namely rock passability, rainfall, soil cover, slope gradient, and unstressed groundwater table depth (Harjanto et al., 2018; Putranto et al., 2019, 2017; Putranto and Aryanto, 2018; Putranto and Purba, 2019). In addition to this spatial approach, the use of stable isotopes in the form of O ($\delta^{18}O$) and deuterium H ($\delta^{2}H$) as natural tracers has also experienced rapid development, especially in the study of groundwater infiltration and flow. (Blasch and Bryson, 2007; Mukherjee et al., 2007; Singh et al., 2013) and in determining the location of groundwater recharge (Ardana et al., 2022; González-Trinidad et al., 2017; Hendrayana et al., 2020; Maria et al., 2021)

Denpasar City is a discharge area from the Denpasar-Tabanan groundwater basin (*Cekungan Air Tanah*). The aquifer in Denpasar City is an area with a wide distribution of unconfined aquifers (Harianja et al., 2014; Suyarto, 2012). Denpasar City has relatively flat topographic conditions with elevations ranging from 0-75 masl, where the recharge area has yet to be identified. Research on the determination of groundwater recharge areas that will later become conservation zones in certain areas has been widely conducted (Harjanto et al., 2018; Putranto et al., 2019, 2017; Putranto and Aryanto, 2018; Putranto and Purba, 2019) but the determination of groundwater recharge areas in a specific zone (in this case in a discharge area with a flat topography in a groundwater basin) has not been done before. Research in determining the recharge area in the discharge area in a groundwater basin, in this case, Denpasar City as a discharge area in the Denpasar-Tabanan Groundwater Basin, to the best of the author's knowledge, has yet to be examined. However, to fill the gap in determining the groundwater recharge area in Denpasar City, it is crucial to conduct this research.

The main objective of this study is to delineate the groundwater recharge zone in Denpasar City, which becomes a discharge area when viewed as a whole in the Denpasar-Tabanan groundwater basin, to support groundwater conservation so that the sustainability and existence of this resource can continue for generations to come. The spatial analysis process is assisted by the application of the Geographic Information System (GIS), which will produce a map depicting the zoning of groundwater recharge, which is expected to be used as a reference by related parties (in this case, the government) in making groundwater management policies and determining patterns of resource conservation to make groundwater resources effectively, efficiently and sustainably.

2. Methods

This research uses a quantitative descriptive method where primary data collection is done through observation, survey, and measurement in the field. Primary data was collected in the form of an inventory of 39 shallow well points out of 294 shallow wells in Denpasar City to measure the depth of the groundwater table. Determining the number of shallow well samples is based on an analysis with the Slovin equation of the population of shallow wells in Denpasar City. In addition, secondary data collection was also carried out in hydrogeological maps, geological maps, soil type maps, slope maps, hydraulic conductivity maps, Denpasar City land use maps, and annual rainfall data. The maps were then interpolated using the Inverse Distance Weighting (IDW) method to obtain the recharge area in Denpasar City. IDW is a deterministic interpolation method that uses the idea that values at points that haven't been sampled can be figured out by adding up values at points that have already been tested. IDW thinks that values from samples closer to the location that wasn't sampled are more representative of the value to be estimated than values from samples farther away (Oktavia et al., 2016). Because of this assumption, observations close to each other will have more weight. Furthermore, the land use map will be overlaid with the map of the recharge area from the analysis as a form of the validation process.

2.1. Research Location

The study area is located in the Denpasar City, Bali-Indonesia which has an area of 31,42 km² and it lies between 08°35'31" - 08°44'49" south latitude and 115°12'09" - 115°04'39" east longitude (BPS Kota Denpasar, 2021). The Denpasar City aquifer is an unconfined aquifer with a modest groundwater level, and it is a highly productive aquifer with flow through fissures and spaces between grains. (Sudadi et al., 1986). This aquifer is part of the Denpasar-Tabanan groundwater basin (Anonim, 2014). Volcanic sediments surround Denpasar, and alluvium and young volcanic sediments are generally highly permeable. In contrast, lower quaternary and tertiary sediments have a broad range of permeability due to their formation. As a portion of Bali island, Denpasar comprises Miocene to Pliocene volcanic products and marine sediment as basement rock, overlain by a thick pyroclastic flow, volcanic products, and volcanic mudflow that originated from intense volcanic activity during The Pleistocene to Holocene of the Quaternary period (Purbo-Hadiwidjojo et al., 1998). Figure 1 shows the location of the study area.

2.2. Data Collection

Sources of data used in this study are divided into primary data and secondary data. The secondary data needed in this research comes from several institutions. The Department of Manpower and Energy and Mineral Resources of Bali Province provided hydrogeological information on geography, geology, topography, and geology. In addition to hydrometeorological data, particularly precipitation data, the Meteorological, Climatological, and Geophysical Agency III of Bali Province provided hydrometeorological data. While the primary data was obtained from the results of field observations. Observation is used to observe non-depressed surface geological features, soil cover conditions, topography, and groundwater table measurements in dug wells (shallow well). There are 39 data collected at random in the research area indicating that the groundwater table is not under pressure. The selected wells data is obtained based on the Slovin formula (Sugiyono, 2019) according to Equation 1. The objective is to determine the hydrogeology type of the boundary. From these boundaries, soil hydraulic characteristics that distinguish studied groundwater basin areas from other groundwater basins can be determined. Weighting (scoring) is used for spatial data processing. Based on Danaryanto et al. (2007) classification, the determination of groundwater recharge and discharge area is based on the five parameters used, such as the hydraulic conductivity (which has the biggest influence), rainfall, soil cover, slope, and shallow groundwater table depth (depth of unconfined groundwater).

$$n = \frac{\mathrm{N}}{1+(\mathrm{N} \times e^2)} \quad (1)$$

Where n is number of samples, N is total population and e is level of error.

2.3. Determination of Groundwater Recharge Area and Discharge Area

According to Lubis (2006) in Murtono et al. (2013), groundwater recharge areas, also known as water catchment areas, can absorb water and subsequently drain it till the water saturation zone. Each location has a unique capacity for water absorption due to its unique set of distinguishing characteristics. Hydraulic conductivity, precipitation, soil cover, slope, and depth of unconfined groundwater are five classification factors for groundwater recharge and discharge zones, according to Danaryanto et al.

(2007). These parameters have varying levels of influence on the infiltration of water into the soil (Table 1). The parameter with the highest weight value primarily affects groundwater basin infiltration (Harjanto et al., 2018; Purnama et al., 2019; Putranto et al., 2017). Tables 2–6 provide the classes of the five parameters based on soil water infiltration.

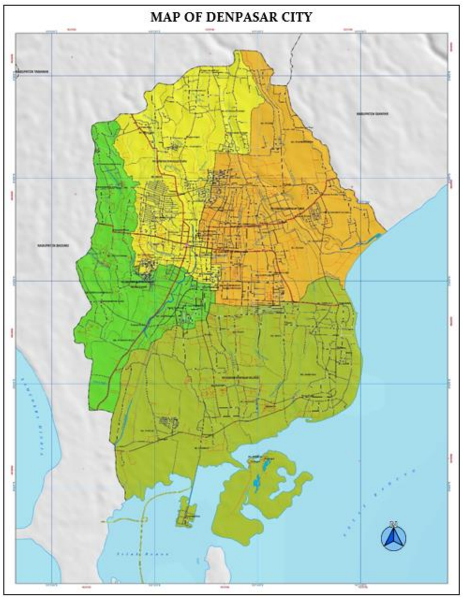

Figure 1. Map of Denpasar City
Source: (Pemerintah Kota Denpasar, 2023)

Table 1. Water infiltration weight value

No	Parameter	Weight Value	
1	Hydraulic conductivity	5	Very high
2	Precipitation	4	High
3	Soil cover	3	Enough
4	Slope	2	Medium
5	Unconfined groundwater level	1	Low

Source : (Danaryanto et al., 2007)

Table 2. Hydraulic conductivity rank value

No	Hydraulic conductivity (m/day)	Weight Value	
1	> 10^3	5	Very high
2	10^1 - 10^3	4	High
3	10^{-2} – 10^1	3	Enough
4	10^{-4} – 10^{-2}	2	Medium
5	< 10^{-4}	1	Low

Source : (Danaryanto et al., 2007)

Table 3. Precipitation rank value

No	Precipitation (mm/year)	Weight Value	
1	> 4,000	5	Very high
2	3,000 – 4,000	4	High
3	2,000 – 3,000	3	Enough
4	1,000 – 2,000	2	Medium
5	< 1,000	1	Low

Source : (Danaryanto et al., 2007)

Table 4. Soil cover rank value

No	Soil cover	Weight Value	
1	Gravel	5	Very high
2	Gravel sand	4	High
3	Sandy clay/sandy silt	3	Enough
4	Clay silt	2	Medium
5	Silt clay	1	Low

Source : (Danaryanto et al., 2007)

Table 5. Slope rank value

No	Soil cover	Weight Value	
1	> 40	5	Very high
2	20 – 40	4	High
3	10 - 20	3	Enough
4	5 - 10	2	Medium
5	< 5	1	Low

Source : (Danaryanto et al., 2007)

Table 6. Unconfined groundwater depth rank value

No	Unconfined groundwater depth (m)	Weight Value	
1	> 30	5	Very high
2	20 – 30	4	High
3	10 - 20	3	Enough
4	5 - 10	2	Medium
5	< 5	1	Low

Source : (Danaryanto et al., 2007)

These steps classify groundwater recharge zones:

a. The process of assigning a weight value to each parameter.
b. Rank each of the criteria.
c. Combining the weight and rating values for each parameter, plus the multiplication results.
d. The results of multiplications between the weight value and the rating value for each parameter are added to classify groundwater recharge regions according to their recharge value. As a consequence, each parameter receives a rating value.

Recharge value = $Kb * Kp + Pb * Pp + Sb * Sp + Lb * Lp + Mb * Mp$..(2)

Where K is hydraulic conductivity, P is precipitation, S is soil cover, L is slope, M is unconfined groundwater depth, b is value weight, and p is value rating

3. Result and Discussion

3.1. Location Overview

Denpasar City is a discharge area from the Denpasar-Tabanan groundwater basin (*Cekungan Air Tanah*). The aquifer in Denpasar City is an area with a wide distribution of unconfined aquifers (Harianja et al., 2014; Suyarto, 2012) which, based on the calculation of the runoff coefficient, has a groundwater potential of 13.75 million m^3/year and CAT of 52.35 million m^3/year (Cahyani et al., 2018) and based on report of JICA (2006) It is stated that the potential of groundwater in Denpasar City is 292 litres/second with a usage of 647 litres/second, so there is a deficit of 355 litres/second. According to Cahyani et al. (2018), domestic water demand in Denpasar City is 65.469 million m^3/year, and non-domestic demand is 1.482 million m^3/year compared to the existing potential. This shows an imbalance between groundwater potential and use. In addition, there was an increase in the population of the City of Denpasar in 2019 of 947,100 people with a population growth rate of 1.77% (Badan Pusat Statistik Kota Denpasar, 2020), which is linear with the increasing need for clean water. To meet the need for clean water, Perumda Tirta

Sewakadarma in 2019 could only serve 87,396 customers, of which 74,170 customers or the equivalent of 296,680 people, were for household needs (Badan Pusat Statistik Kota Denpasar, 2020). So it is estimated that the dominant community uses other water sources such as groundwater (drilled wells or dug wells) in fulfilling clean water. Changes in land use in Denpasar City are also very concerning where green open areas are dominated in the northern area of Denpasar City, which has the main aquifer lithology of the Buyan, Bratan and Batur volcanic rock groups, which are composed of tuff and lava (Purbo-Hadiwidjojo et al., 1998) and is an aquifer with flow through gaps and spaces between grains which is highly productive (Politeknik Negeri Bali, 2014), has changed 7.38% to become a residential area during 2014-2019 (Badan Pusat Statistik Kota Denpasar, 2020). Based on these considerations, the Denpasar City aquifer is included in the aquifer prone to water deficits with high levels of groundwater stress. The high level of water demand, especially groundwater, greatly influences groundwater availability. Its availability is closely related to the process and amount of groundwater replenishment; the quantity and area in Denpasar City are uncertain.

3.2. Geographic Information System (GIS)

GIS is a system for inputting, calculating, collaborating and generating data with geographical references. The recent geographic analysis relies heavily on spatial data. In the GIS method, both primary and secondary data are utilized. This study's primary data include the locations of shallow wells in the city of Denpasar, where the depth of the phreatic surface will be measured. Secondary data consists of the Administrative Map of Denpasar City, the Geological Map (hydraulic conductivity) to determine rock graduations, the Rainfall Map to determine the amount of rainfall in the study area, the Indonesian Rupa Bumi Map (RBI) to determine populated areas and open spaces, the Contour Map to determine the slope angle of the study area, and the Land Cover Map to determine the type of soil in the study area. The maps were then interpolated using the IDW method to obtain the recharge area in Denpasar City and validated with the land use map of Denpasar City.

5.3. Denpasar City Well Distribution Map

The data in this study pertain to all shallow wells in the Denpasar City Region, totaling 294 shallow wells (Politeknik Negeri Bali, 2014). Regarding the samples evaluated in this study, estimating the number of samples from a population uses the Slovin formula, as shown in Equation 1. This study also employs quota sampling as a sampling methodology, which determines the number of populations with specific characteristics up to the target number (quota) (Sugiyono, 2019). A sample of 39 shallow wells was selected from a total population of 294 shallow wells from all villages, the number of which was decided by the quota established in each subdistrict in the Denpasar City region.

Table 7. Number of samples

District	Number of Well	Calculation	Total of Samples (rounded)
North of Denpasar	64	64/294 x 39= 8.4	8 shallow wells
East of Denpasar	50	50/294 x 39= 6.6	7 shallow wells
South of Denpasar	112	112/294 x 39= 14.8	15 shallow wells
West of Denpasar	68	68/294 x 39= 9.0	9 shallow wells

From the sample points of shallow wells taken using a handheld GPS, coordinates are obtained, which will later place a point on the map where the following point meets the vertical and horizontal lines on a map, which is then inputted into the Geographic Information System (GIS) to produce a map of the distribution of shallow well points as shown in Figure 2. The South Denpasar sub-district has 112 shallow wells, 15 of which were sampled. The existence of many shallow wells in South Denpasar, combined with the surface elevation and hydrogeological cross-section, showed that the land surface in this area tends to be flat compared to other sites, causing water, both surface and groundwater, to flow from higher to lower places, causing the groundwater level to be shallow.

5.4. Determination of Groundwater Recharge Area in Denpasar City

Determination of groundwater recharge areas in Denpasar City with several levels of analysis that will be carried out in harmony. The analysis step begins with identifying, processing, and analyzing the determining parameters. Danaryanto et al. (2007) sources the determination of these parameters. The determining parameters in determining the groundwater recharge area in Denpasar City are:

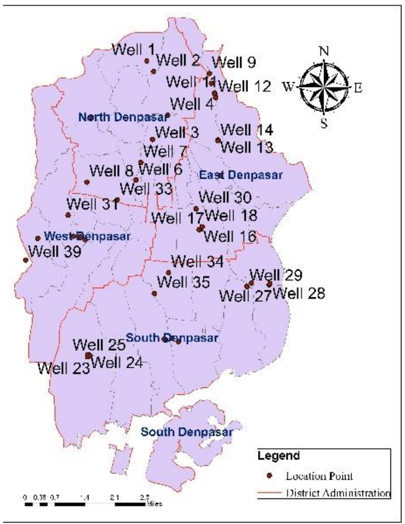

Figure 2. Map of well location points

1. Hydraulic conductivity parameters

Lithology is the most influential parameter in determining the groundwater recharge area in Denpasar City, where the capacity of rock becomes a medium for storing and flowing water. This lithology parameter has the highest number of points, which is 5. Lithology is strongly influenced by the layers and texture of a rock; the higher the permeability value of a rock type, the higher the value obtained. Most of the lithology found in the study area is the product of old volcanoes consisting of very compact volcanic breccias, solid lava, and tuff. The hydraulic conductivity in North and East of Denpasar is 1.10-2.81 mm/hour ($2.64 \times 10^{-2} - 6.744 \times 10^{-2}$ m/day), South Denpasar is 1.10-2.12 mm/hour ($2.64 \times 10^{-2} - 5.1 \times 10^{-2}$ m/day), and West Denpasar is 1.10-1.66 mm/hour ($2.64 \times 10^{-2} - 3.984 \times 10^{-2}$ m/day), which is in the medium category (Politeknik Negeri Bali, 2014). Then an assessment is carried out with Formula 2. It can be seen in Figure 3 and Table 8.

Table 8. Calculation of conductivity hydraulic parameter score

Hydraulic conductivity	Rating value	Weight value	Score
$10^{-2} - 10^{1}$	3	5	15

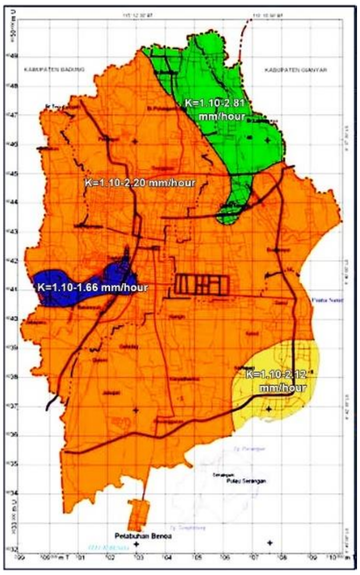

Figure 3. Map of hydraulic conductivity
(Sources: Politeknik Negeri Bali, 2014)

Based on Figure 3, the hydraulic conductivity values are 1.1 - 2.81 mm/h and 1.1 - 2.20 mm/h in the North Denpasar area, 1.1 - 1.66 mm/h in the West Denpasar area, and 1.1 - 2.12 mm/h in the South Denpasar area, respectively (Politeknik Negeri Bali, 2014). Hydraulic conductivity is the ability of a rock to drain groundwater at a specific rate. The North Denpasar area has the highest hydraulic conductivity value, which means that the morphological composition of the soil and rocks can drain groundwater well. This is consistent with the Bali Sheet Hydrogeology Map (Sudadi et al., 1986), where the North Denpasar area is dominated by aquifers that flow through fissures, fractures and channels. In contrast, the South Denpasar area is an aquifer that flows through fissures and interstices. Groundwater flow is determined by hydraulic conductivity and hydraulic gradient. The hydraulic gradient is the change in the head (drop in groundwater level) per unit distance. The greater the hydraulic conductivity value, the lower the flow resistance. The force of gravity causes groundwater to flow through an aquifer along a hydraulic gradient from high head to low head, generally (for unconfined aquifers) corresponding to the slope of the land surface (Moore, 2012). Areas that have potential as groundwater recharge areas have fast - relatively fast infiltration rates, high - very high hydraulic conductivity, and are composed of rocks with good porosity (Purnama dkk., 2019).

2. Precipitation parameters

The amount of water that seeps into the ground is due to the large amount of rain that falls. If it rains a lot or for a long time, the water absorbed by the soil will be even more. Because it shows the amount of water that can seep into the groundwater system, its value increases with increasing rainfall duration. The Center for Meteorology, Climatology and Geophysics Region III (BMKG Region III) obtained rainfall values in Denpasar City. The observation locations were at the Sumerta rainfall station in East Denpasar District, the Abiansemal rainfall station in Abiansemal District, and the Sanglah rainfall station in West Denpasar District. According to the results of the classification of the value of the total rainfall for a year, this rainfall becomes one level, namely in the range of 1,000-2,000 mm/year, the calculation in Table 3, which belongs to rank two in the classification of rainfall. The results of calculations using Equation 2 can be seen in Table 9 and then inputted into the Geographic Information System (GIS) to produce a rainfall map like Figure 4, namely on a map of rainfall parameter values.

Table 9. Calculation of precipitation parameter score

Precipitation (mm/years)	Rating value	Weight value	Score
1,000 – 2,000	2	4	8

Based on Figure 4, it can be seen that the highest annual average rainfall (1,900 - 2,000 mm) is dominated in the East Denpasar area, and the area with the lowest average yearly precipitation (1,500 - 1,600 mm) occurs in parts of North Denpasar, West Denpasar, and South Denpasar. This rainfall parameter has a weight value of four (4) and is the most significant parameter number two (2). Based on the results of the classification of the value of the amount of rainfall during the year, the delineation of the area on this rainfall parameter into one class, namely in the range of 1,000-2,000 mm/year, which is included in the second rank in the classification of rainfall. This is because the research data shows values ranging from 1,500 to 2,000 mm/year, causing it to have the same score value of eight (8). This is in accordance with the classification of rainfall in determining the recharge area by Danaryanto (Danaryanto et al., 2007), where it is stated that precipitation with an intensity of 1,500 - 2,000 mm/year is included in the medium classification and has a weight value equal to two.

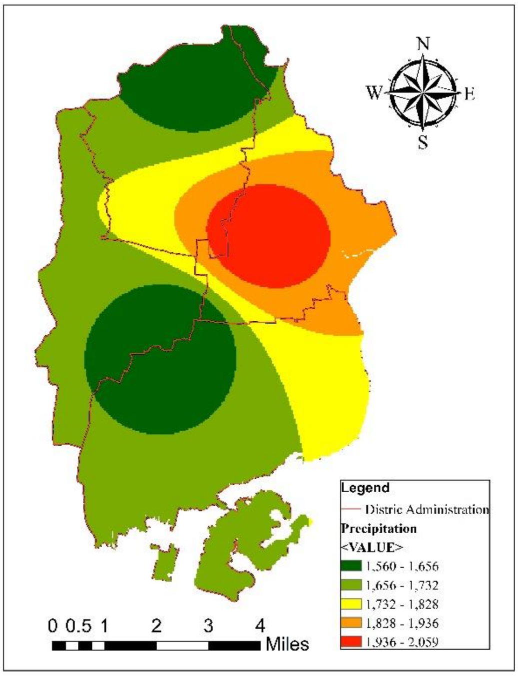

Figure 4. Map of precipitation

3. Soil cover parameters

Denpasar is the region covered by volcanic sediments and generally, alluvium and young volcanic sediments are highly permeable, and lower quaternary and tertiary sediments have wide-ranging permeability due to the formation. Denpasar as a part of Bali island consists of Miocene to Pliocene volcanic products and marine sediment as basement rock, overlain by a thick pyroclastic flow, volcanic products (sandy clay/sandy silt) and volcanic mudflow that originated from intensive volcanic activities in The Pleistocene to Holocene of Quaternary period (Purbo-Hadiwidjojo et al., 1998). Using Equation 2, a score of 6 is given for the type of sandy clay or sandy silt cover in the study area. Calculations and scores can be seen in Table 10 and soil cover map can be seen in Figure 5.

Table 10. Calculation of soil cover parameter score

Soil cover	Rating value	Weight value	Score
Sandy clay/sandy silt	3	3	9

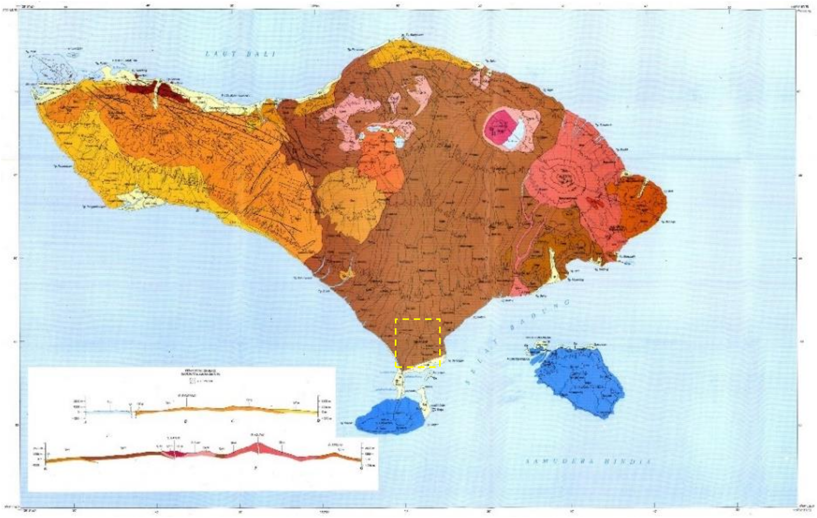

Figure 5. Map of Bali Geology
(Sources: Hadiwidjojo, M.M.P. Samodra and Amin, 1998)

The study area is dominated by sandy clay/clay silt, with a score of 3. This area is scattered throughout Denpasar City and consists of brown latosol soil-like clay and regosol. Based on Table 10 and Figure 5, the rating value of this soil cover is three, and the weight value is two, which eventually gave a score of 9 for the type of sandy clay or sandy silt cover in the study area. Based on the classification of soils with the USCS (Unified Soil Classification System) system, sandy clay or sandy silt includes in the gravel a lot of fine grain content, which in the sieve test obtained sand more than 50% of the coarse fraction passes sieve no. 4 (4.75 mm) (Hardiyatmo, 2002). This is consistent too with the Bali Sheet Hydrogeology Map (Sudadi et al., 1986), where the North Denpasar area is dominated by aquifers that flow through fissures, fractures and channels. This means this soil is still good enough to pass water.

4. Slope parameter

The slope of an area will greatly influence the process of water absorption. The amount of water that seeps into the ground will be easier the higher the slope value. For various types of slopes, the infiltration factor also affects the slope of this slope. Based on Figure 6, it can be seen that the elevation of the North Denpasar sub-district area is at an elevation of 25 - 75 m.a.s.l while other sub-district regions such as South Denpasar sub-district have elevations lower than 25 m.a.s.l, West Denpasar sub-district has the highest elevation at 25 m.a.s.l, and East Denpasar sub-district is at an elevation of 12.5 - 37.5 m.a.s.l. Based on the Table 8, the difference in the degree of slope of the research location can be divided into five categories. The first area, South Denpasar District has a slope value of < 5°. This segment value is 2. The second location has a slope of 5° - 10°with a value of 4 after being multiplied by the slope weight value in West Denpasar District, East Denpasar District, and North Denpasar District. However, the highest elevation in Denpasar City is dominated in the North Denpasar Sub-district area, with an altitude of 25 - 75 m.a.s.l. This corresponds to the research results by Irmayanti et al. (Irmayanti et al., 2020), which state that the height > 50 m.a.s.l or slope > 8% in Denpasar City is 9.72 km2 of Denpasar City area or 7.61% of the total area of Denpasar City where the arena is in North Denpasar Sub-district. Table 11 and Figure 6 shows the results of calculations.

Table 11. Calculation of slope parameter score

Slope	Rating value	Weight value	Score
$>40^0$	5	2	10
$20-40^0$	4	2	8
$10-20^0$	3	2	6
$5-10^0$	2	2	4
$< 5^0$	1	2	2

5. Unconfined groundwater depth parameters

The shortest distance between the ground surface and the groundwater table is the depth of the groundwater table. It will be easier for water to escape or move to another location the deeper the groundwater table. The groundwater catchment area will be more distinct the deeper the groundwater table. The fifth parameter is the depth of the groundwater table, with a value of one representing the lowest value. This single value results in this parameter having the most negligible impact on research and being the least specific when identifying groundwater catchment areas.

The depth of the groundwater table is the minimum distance from the ground to the groundwater table. The deeper the water table, the easier it is for water to escape or migrate vertically into the soil. The shallower the water table, the more the groundwater recharge area will be characterized. From the groundwater level measurements, there is data on the depth of the groundwater level which ranges from 0.55 - 8.02 meters. Based on the interpolation results, areas with shallow groundwater depth with a value range of 0.55 - 2.16 meters are in the North Denpasar area, East Denpasar, and a small part of South Denpasar. In contrast, areas with shallow groundwater depths of 4.27 - 8.02 meters are in a small area of the West Denpasar and East Denpasar areas. The results of the calculations can be seen in Table 12.

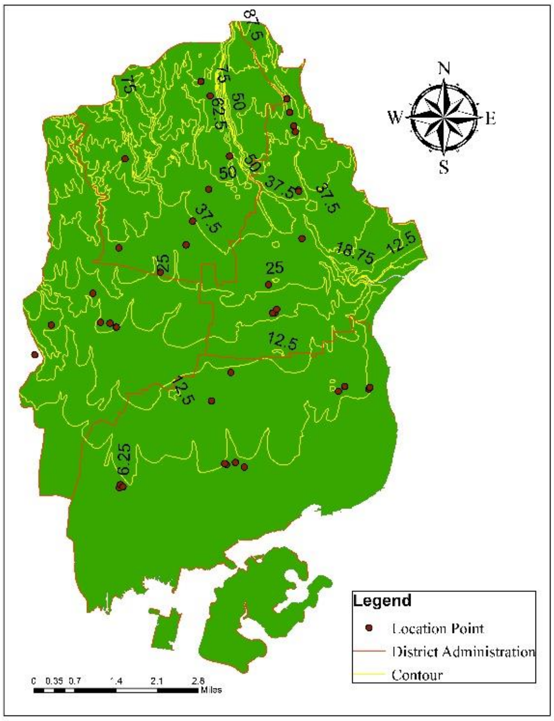

Figure 6. Map of Denpasar City slope

Table 12. Calculation of unconfined groundwater depth parameter score

Unconfined groundwater depth (m)	Rating value	Weight value	Score
5 – 10	2	1	2
< 5	1	1	1

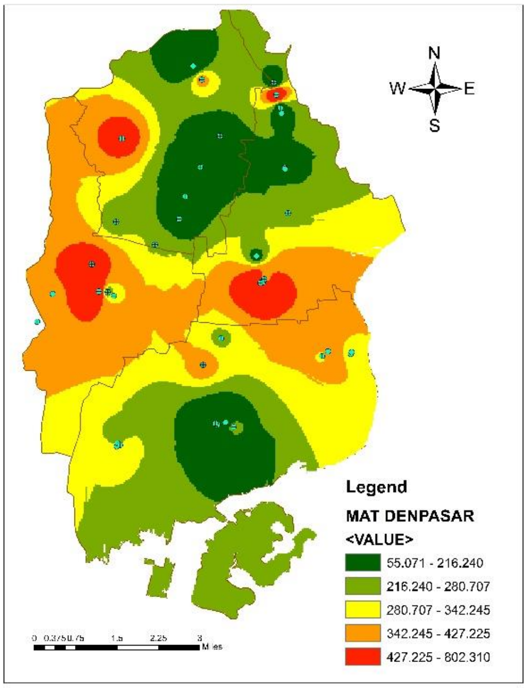

Figure 7. Map of unconfined groundwater depth

According to Danaryanto et al. (2007), field research can be divided into two parts. The four districts of Denpasar City have an area with a score of 1 and a depth of fewer than 5 meters, with a value range of 0.55 - 2.16 meters (Figure 7). The area with a depth of fewer than 5 meters is the North Denpasar District, East Denpasar District, and West Denpasar District are some examples. An area with a depth of 5 to 10 meters has a rating value of 2, so if multiplied by the weight value, it will get a score of 2. Table 12 shows how to use Formula 2 to calculate it. In addition, as depicted in Figure 7, it is entered into a Geographic Information System (GIS) to produce a phreatic depth map.

6. Groundwater Recharge Area and Discharge Area

The weighting value of each parameter multiplied by the ranking value is the result of the weighting. According to Danaryanto et al. (2007), the area with the highest number of values can become an infiltration area, then the area with the lowest value is a discharge area. In this study, groundwater in Denpasar City was divided into four regions: North Denpasar, East Denpasar, South Denpasar, and West Denpasar Districts. Using the Geographic Information System (GIS), namely the Weighted Overlay Sum with Inverse Distance Weighted (IDW) Interpolation Method, which produces a map of the distribution of groundwater recharge areas in Figure 8, and using the calculation of equation 2 will create a total value as shown in Table 13:

Table 13. Total calculation of groundwater recharge and discharge area

District Area	Total Value
North of Denpasar	46
East of Denpasar	38
West of Denpasar	38
South of Denpasar	36

From the weighting results of each study area, the maximum value obtained was 46 in North Denpasar District, while the minimum value found in the South Denpasar District area was 36. The limiting value between the recharge area and the discharge area was 41. The area with a value of 41 - 46, those with capacity, are the main recharge areas, while areas with a value of 36 - 41 are groundwater discharge areas. Based on the total value, the groundwater recharge area is in the North Denpasar area, and the discharge area is dominated by the South Denpasar areas. Then the results of the weighting of the values for each parameter of the analysis area are input into the Geographic Information System (GIS) on the ArcGIS 10.8 application layer by adding Denpasar City Map data in shp format. Coordinate point data and parameters for determining the recharge area into the shp file, then analyze using Interpolation Inverse Distance Weighted (IDW).

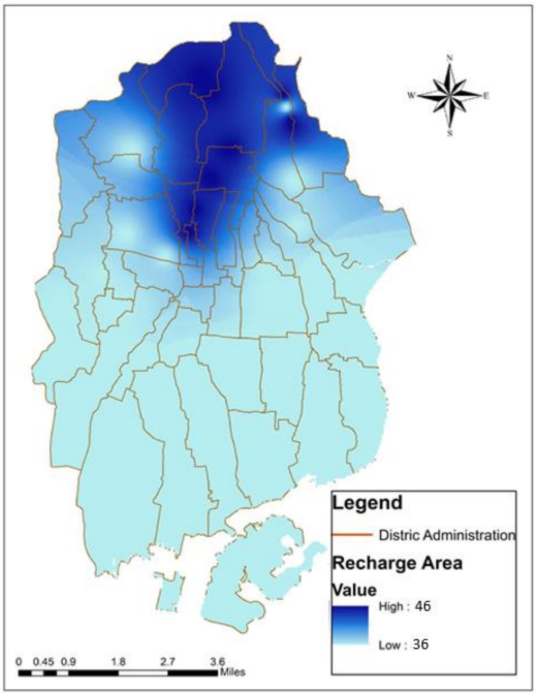

Figure 8. Map of recharge area and discharge area in Denpasar City

The resulting weighted values can be divided into two types: the affluent and releasing areas. The release areas have a final score from the weighting results between 36-41. Based on the weighting results, the release areas are located in the West Denpasar sub-district and South Denpasar sub-district. These areas are located in areas with flat volcanic morphology and has a relatively flat elevation (slope < 5%). This area is dominated by latosol soil types and a small portion of alluvial in coastal regions of South Denpasar. Based on the weighting results, the recharge area is located in the North Denpasar Subdistrict, namely the Peguyangan area, and part of East Denpasar, namely the Penatih area (Figure 8). This area has a weighting value of 41-46. This area has a high weighting value because it consists of young volcanic product consisting of volcanic breccias, sandy tuffs with laharic deposits and is an aquifer with flow through fissures and interstices with high productivity and wide distribution so that it tends to be easy to channel water due to good porosity and permeability. In addition, this recharge area has a relatively higher elevation with slope range from 8-10%. The delineation of the recharge and discharge areas also corresponds to the principle of gravity transports of groundwater. The driving force of gravity transports groundwater through aquifers along the hydraulic gradient from areas of the high head to regions of the low head, generally (for unconfined aquifers) according to the land surface slope (Moore, 2012).

7. Validation of groundwater recharge area

After the recharge and discharge zones are classified, it is continued to adjust the land following these zones as a form of the validation process. This is done to maintain water resources in the Denpasar City area. Not all areas have the proper land use function in the recharge area. Appropriate land use is in the form of green lanes in the form of rice fields, while inappropriate land use is in the form of large settlement areas because it will reduce water entering the soil. Meanwhile, the discharge area in Denpasar City, located in the West Denpasar District and South Denpasar District area based on the land use map, is dominated by dense residential areas, has a relatively flat elevation (slope < 5%), and has a hydraulic conductivity value $2.64\times10^{-2} - 5.1\times10^{-2}$ m/day.

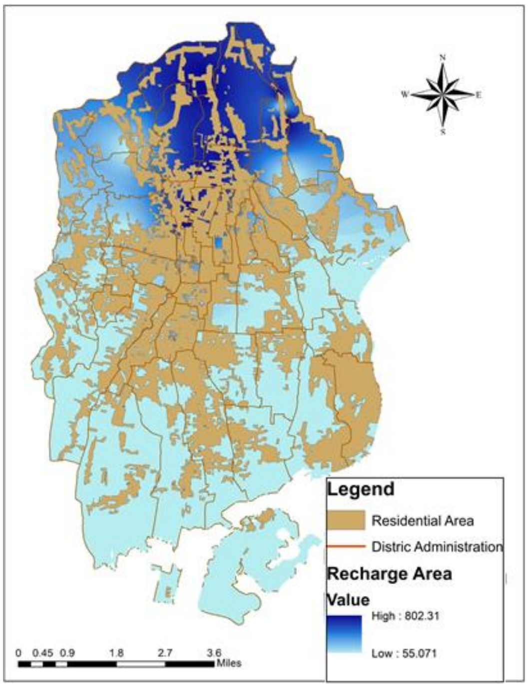

Figure 9. Validation of groundwater recharge area

The recharging area validation test also conducted by merging the Denpasar City groundwater recharge area map with the hydraulic conductivity map, which is the parameter with the highest value in determining the distribution of recharge area distribution, and the Denpasar City land use map. The data indicate that the recharge area is in a zone with the highest water infiltration (evidenced by the highest hydraulic conductivity value among other areas, which amounted to $2.64\times10^{-2} - 6.744\times10^{-2}$ m/day) and open space, specifically rice fields has a relatively higher elevation with slope range from 8-10%. They validated the findings of determining the recharge area by comparing the recharge and discharge area map with the map of hydraulic conductivity and land use. Figure 9 demonstrates the effects of the overlay.

4. Conclusions

Determination of recharge and discharge areas in Denpasar City groundwater has five parameters, namely lithology consisting of 1 class ($10^{-2} - 10^{1}$ m/day); rainfall consists of 1 class (1000-2000 mm/year); there is 1 class of soil cover (sandy clay/sandy silt); slope gradient consists of 2 classes 5-10° and <5°); and there are two classes of unconfined groundwater depth (5-10 m, <5 m). The result of the sum of the values in the parameters, the values obtained are 36-46. The limit to distinguishing the recharge area from the discharge area is 41. The recharge area with 41-46 is located in the northern of Denpasar City. Furthermore, there is a value of 36-41 located in southern of Denpasar City for discharge areas. Determining recharge and discharge areas can help the government plan regional spatially. Protect the groundwater recharge area and track development. To avoid reducing groundwater quality and availability in Denpasar City, the discharge area must be monitored for groundwater consumption and utilisation. This study also suggests using an infiltration well or bio-pore method to conserve groundwater in Denpasar City.

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