Post-Earthquake groundwater potential analysis in Mamuju Regency, West Sulawesi

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ABSTRACT

The earthquakes that occurred in January 2021 at Mamuju, West Sulawesi not only caused damage to buildings but also destruction of water facilities. Thus, question is raised about the changes of groundwater quality in the area. This study aims to follow up this question by conducting the geoelectric measurement, pumping test, and water quality analysis. Based on the resistivity values of geoelectrical data, each area has aquifers in different stratigraphic layers of (1) calcareous sandstone of the Mamuju Formation, (2) lapilli rock of the Gunung Api Adang Formation, (3) breccia of the Gunung Api Adang Formation and (4) sandstone of the Alluvium deposit. These aquifers are mainly confined and were grouped into the shallow (less than 25m deep) and deep (more than 25m deep) aquifers. Water quality from the groundwater wells meet the criteria of Environmental Health Quality Standards, except for one well GL03-PLDA that has high Manganese content. Determined discharge values suggest that water resources are enough to support around 3916 people or 999 settlements in Mamuju District and about 11664 people or 2916 settlements in Simboro District.

Keywords: *groundwater, aquifer, geoelectric, water quality*

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INTRODUCTION

Water is one of the basic needs that affect life and humanity. However, freshwater accounts for only 1% of the total water on Earth. A good quality of fresh water is necessary for humans, animals, and plants in sustaining their lives. In Indonesia, the use of water is regulated by Indonesian Law (Undang Undang) No. 17 of 2019 which discusses water resources including groundwater, the soil and subsurface rocks layers.

Groundwater occupies the voids or pores between grains in the rock layers under saturated conditions. Groundwater analysis is needed to investigate the quality of freshwater. It is commonly done by drilling groundwater wells. Below the surface earthquakes can expose groundwater to pollution where open fractures can release fluids and alter streamflow from aquifers.

The earthquakes that occurred on 14, 15 and 16 January 2021 in Mamuju, West Sulawesi not only caused damage to buildings but also destruction of water facilities. Thus, questions were raised about disruption of aquifers caused by earthquakes and its effect on drinking water quality. This study attempts to address these questions by conducting geoelectric measurement, pumping test and water quality analysis in Mamuju and Simboro Districts (Figure 1).

REGIONAL GEOLOGY

Regional Tectonics

Sulawesi is situated at the triple junction between the Eurasian, Australian and Philippine Sea plates.

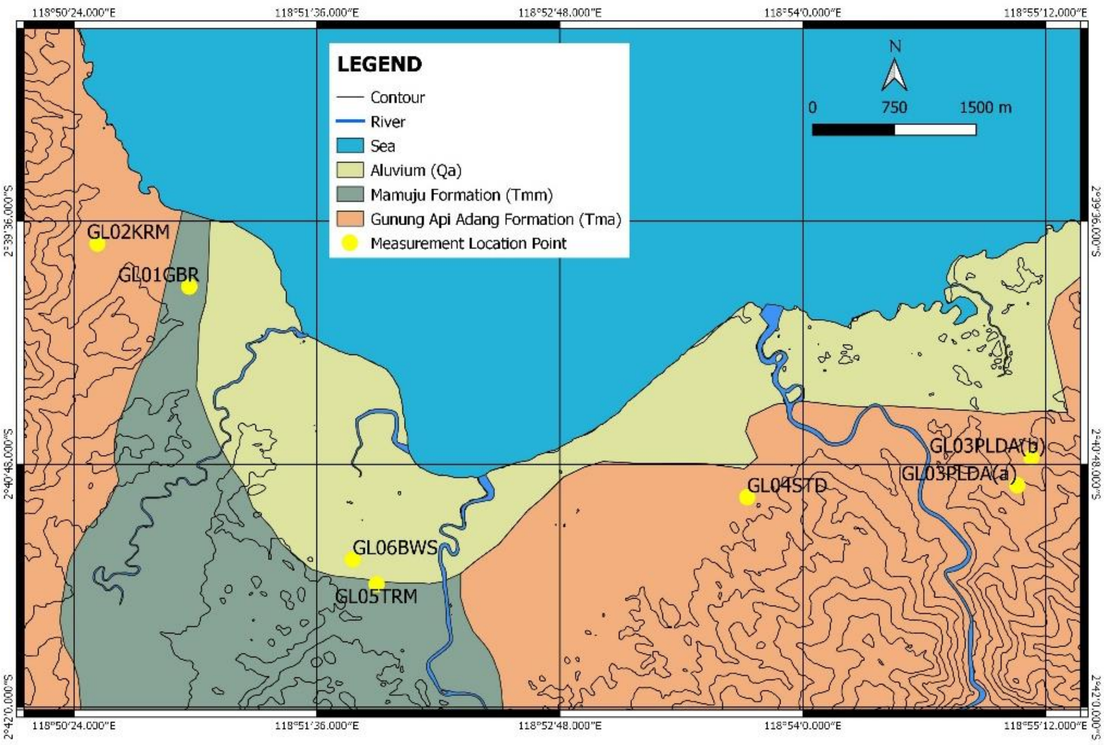


Figure 1: *Map showing the study area and site locations (yellow dots).*

This complex geology was often interpreted as a simple convergent arc-ophiolite-continent tectonic configuration resulting from a single arc-continent collision (e.g. Hamilton, 1979; Silver et al., 1983). West Sulawesi was affected firstly by Palaeogene extension which eventually led to the formation of the Makassar Straits. Secondly, it was influenced by Neogene contraction and lift due to the Sula Spur collision in the Early Miocene (Hamilton, 1979; Bergman et al., 1996; Calvert and Hall, 2007). The Early Miocene collision of the Sula Spur microcontinent (Klompé, 1954) and the North Arm volcanic arc (Hall, 2002) was followed by extensional fragmentation of the Sula Spur microcontinent because of Banda subduction rollback (Honthaas et al., 1998; Spakman and Hall, 2010; Hall, 2012; Hennig et al., 2016; Zhang et al., 2020; Nugraha et al., 2022).

Regional Stratigraphy

The stratigraphy at the Mamuju Regency consists of (1) Adang Volcano Rock Formation, (2) Mamuju Formation, and (3) Quaternary Alluvium (Figure 1; Ratman and Atmawinata, 1993; Armstrong, 2012). (1) Adang Volcano Rock Formation (Tma; Late Miocene) is composed of mainly leucite and breccia basalt lava rocks with a wide distribution. (2) Mamuju Formation (Tmm; Late Miocene) consists of rock calcareous sand, tuffaceous marl, sandy limestone with tuff insertion, and marl. (3) Alluvium (Qa; Holocene) is the youngest deposit and is composed of sediments on rivers, beaches, and mountains.

METHODS

Geoelectric

Resistivity in the geoelectric method is used to determine rock electrical properties by conducting an electrode current into the ground. The rock resistivity value is influenced by several factors including water content, rock porosity, and solubility of salt. 1D Geoelectric data acquisition were measured from 7 locations and were processed using IP2WIN software (Figure 2).

Pumping Test

Two types of pumping test that were used in this study are:

a. *Well Test*

Well test was used to determine potential well type capacity (Qs) by subdividing pumping discharge (Q) with water level subsidence (S). The capacity of the well type (Qs) can be expressed by the equation (Bisri, 2012):

$$Qs = \frac{Q}{S} \qquad (1)$$

where:
Qs = Well type capacity (m^2/day)
Q = Pumping discharge (m^3/day)
S = Water level drop (m)

b. *Aquifer Test*

Aquifer test was carried out to determine the capacity of the layer to carry water (aquifer), the transmissivity value of the aquifer (T),

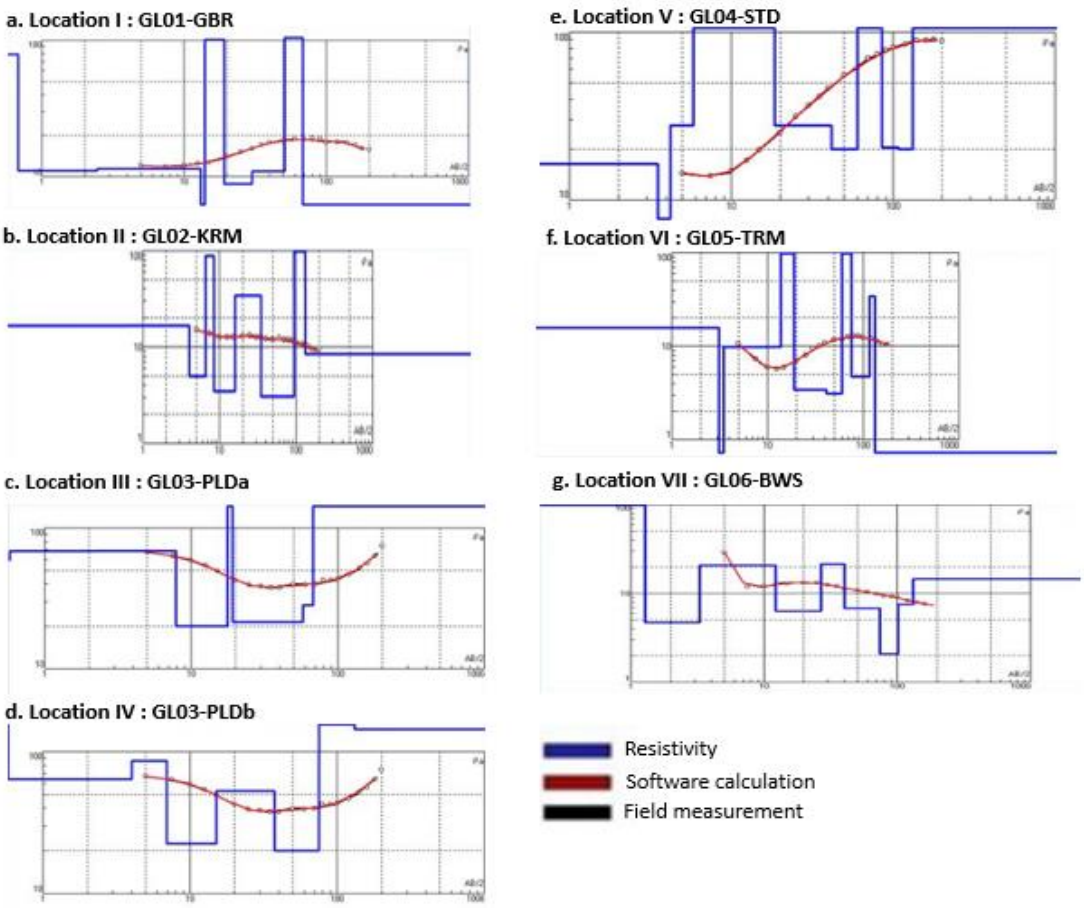


Figure 2: *Graphic display of geoelectric processing results in each well location*

and the coefficient value water flow (K). Aquifer tests are subdivided into:

- Constant Rate Test

  Constant rate test is a continuous pumping test with a fixed discharge in several wells.

- Recovery Test

  This test is used to test the recovery from a soil's water level soil at the time, before and after pumping.

Water Quality Analysis

Water quality assessment is carried out at the laboratory of West Sulawesi Provincial Health Office and includes analyses of physical and chemical parameters.

RESULTS & INTERPRETATION

Geoelectric

Geoelectric measurements were conducted from 7 locations in the Mamuju area (Figure 1) and are summarized in Table 1 and Figure 2. The maximum penetration depth is 133.33 meters with error values ranging between 0.508 % and 0.924%. There are up to 10 lithological layers that were observed based on its resistivity value of Palacky (1988). These lithologies can be grouped into Aquitar, Aquiqlud, Aquifug, and Aquifer systems. Aquifer is a non- or less consolidated layer or formation with saturated water conditions that can store and pass water. Aquiqlud is a layer or formation in geological units in saturated water conditions that can store water but cannot pass water because of its very low hydraulic conductivity value (impermeable). Aquitar is a layer or formation in which can store and release water under certain conditions (semi-impermeable layer). It has a small hydraulic conductivity value so that the water flow moves slowly but still has a possibility to flow water. Aquifug is a layer or formation that cannot store and pass water. The water that is not absorbed on the surface becomes surface flow.

In general, we classified the aquifer depth into: (1) shallow aquifers which are free aquifers with depth less than 25m from ground level; and (2) deep aquifers which are semi-depressed and depressed aquifers with depths more than 25m below ground level (Table 1).

Lithostratigraphic Correlation

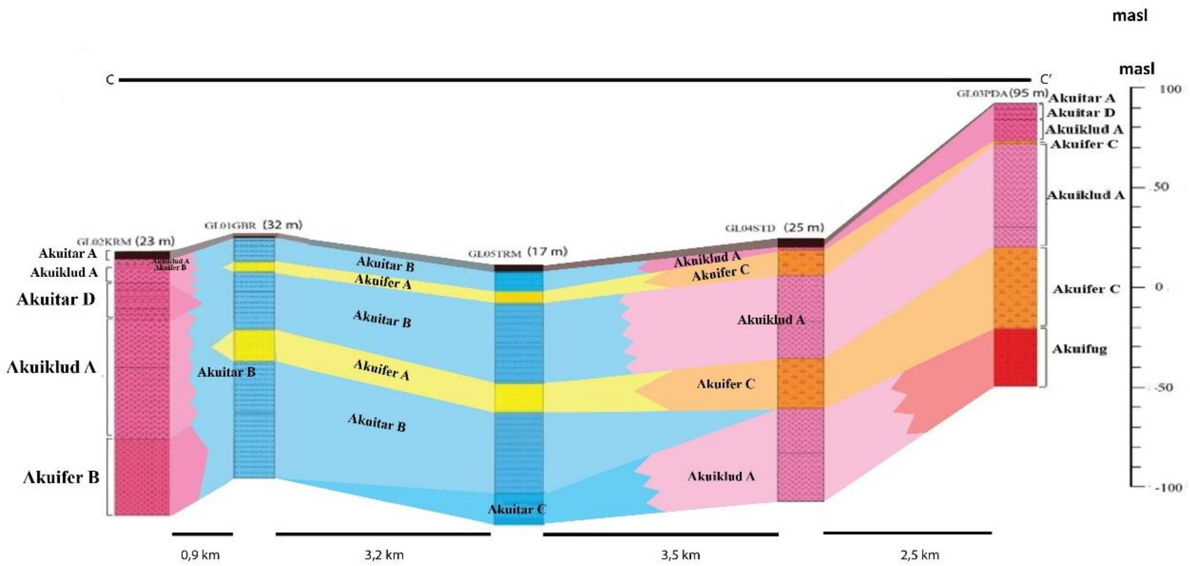
A 2D stratigraphic correlation was made from five geoelectrical measurement logs (Figure 3) to show the distribution of different lithologies and aquifer types. Figure 3 shows correlated aquifers for GL01-GBR, GL05-TRM, GL04-STD, and GL03PLDA(a) wells.

The shallow aquifer layer has a maximum depth of 19.2 meters below Ground Level (m GL) and is observed in the GL01-GBR, GL05-TRM, GL04-STD, and GL03PLDA(a) wells. This layer is pinching out to the west and includes breccia and limestone of the Gunung Api Adang and Mamuju formations respectively.

The deeper aquifer layer has the minimum depth of 51.93 m GL and is generally located 30m below the shallow aquifer. This aquifer is lithologically similar to the shallow

Table 1. Aquifer depth at each geoelectric measurement well locations (m GL)

No	Name	Location	Aquifer Type Shallow aquifer (<25m GL)	 Deep aquifer (>25m GL)
1	GL01 GBR	Governor Office of West Sulawesi	13.97 m – 19.16 m	51.06 m – 68.40 m
2	GL02 KRM	TNI KOREM 142 TATAG, Mamuju, W. Sulawesi	6.54 m – 8.446 m	94.05 m – 132.6 m
3	GL03 PLDA(a)	POLDA (Regional Police Headquarter) of W. Sulawesi	17.63 m – 19.20 m	67.78 m – 105.9 m
4	GL03 PLDA(b)	Helipad, POLDA of West Sulawesi	-	75.70 m – 100.0 m
5	GL04 STD	Manakarra Stadium, Mamuju, West Sulawesi	5.803 m – 18.47 m	60.33 m – 85.47 m
6	GL05 TRM	Mamuju Bus Station, West Sulawesi	13.71 m – 19.10 m	60.04 m – 74.66 m
7	GL06 BWS	Office of BWS III, Mamuju, West Sulawesi	3.265 m – 12.28 m	26.93 m – 40.02 m



Lithology	System	Symbol
Topsoil	Aquitar	
Limestone	Aquifer	
Lapili Rock	Aquifer	
Marl Tuff	Aquitar	
Marl		
Tuff Lapili		
Tuff	Aquiqlud	
Breccia	Aquifer	
Lava	Aquifug	

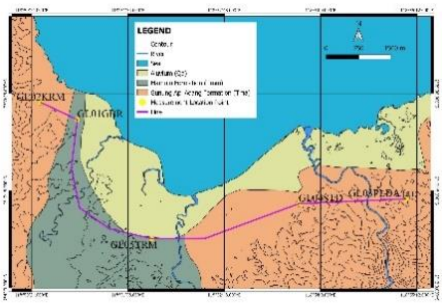


Figure 3: *2D stratigraphic correlation across the well locations where geoelectric measurements took place.*

unit and is pinching out to the west too.

Pumping Test

Pumping tests were carried out in five locations to determine the discharge (Q), water level drop (Sw) and specific capacity (QS) as shown in Table 2. Ground water level subsidence (s) and time (t) of the well pumping test well is summarized in Figure 4. Semi-log plot on Figure 4 shows a linear relationship at the end of the pumping test that indicates confined aquifers.

The values of water level subsidence were used to calculate transmissivity following the Jacob's method (Kruseman dan de Rider, 2000). Transmissivity ranges from 21,095.5 to 101.3 m^2/day and is higher within the carbonate aquifer in GL01GBR and GL02-KRM wells (Table 3).

Groundwater Potential

Groundwater potential at the study area was determined based on slope level, geomorphic lineament, drainage system, overburden, and aquifer thicknesses for the shallow (Figure 5) and deep aquifers (Figure 6).

Groundwater potential is generally lower in the area with a higher slope.

Table 2. Values of pumping discharge (Q), water level drop (Sw) and specific capacity (Qs)

No	Well Code	Q (m^3/s)	SW Optimum (m)	Qs (m^2/s)
1	GL01GBR	0.3	13.0 m	0.02
2	GL02- KRM	7.5	3.0 m	2.50
3	GL03-PLDA (a)	1.0	2.5 m	0.40
4	GL04- 0STD	2.7	6.5 m	0.40
5	GL05-TRM	3.0	6.0 m	0.50

Table 3. Values of residual drawdown difference (S), transmissivity (T) and interpreted groundwater potential

Well Code	S	T (m^2/day)	Groundwater Potential (Domestic)
GL01GBR	4.7	101.3	Very Well
GL02-KRM	1.4	84,358.9	Very Well
GL03-PLDA (a)	1.5	10,547.7	Very Well
GL04-0STD	3.0	14,239.4	Very Well
GL05-TRM	2.25	21,095.5	Very Well

The weighting was calculated by dividing the level of the slope and the degree of slope. The study area is dominated by a weight value of 2 to 5 (from orange to green, Figures 5 and 6). To sum up, only GL03PLD is located on the higher slope.

Groundwater potential is usually higher in the area with straight geomorphic lineaments. The weight value of 1 is marked in green and indicates that there is no straightness. The value of 2 is marked with red and suggests the presence of straight geomorphic lineaments (Figures 5 and 6).

Drainage system was used to differentiate between the main and branch of a river. Groundwater potential will be higher for the main river flow that is indicated by pink, whereas blue indicates a branch of a river (Figures 5 and 6).

Overburden thickness affects the ability of layers to pass and store water. Overburden thickness from geoelectrical resistivity analysis is also divided into shallow (Figure 5) and deep aquifers (Figure 6). Ground water potential will be higher in the higher value of overburden thickness. The weight value of 1 has less than 6m overburden thickness (shown by white). The weight value of 2 has overburden thickness between 6m and 25m (red). The weight value of 3 has more than 25m overburden thickness (dark red).

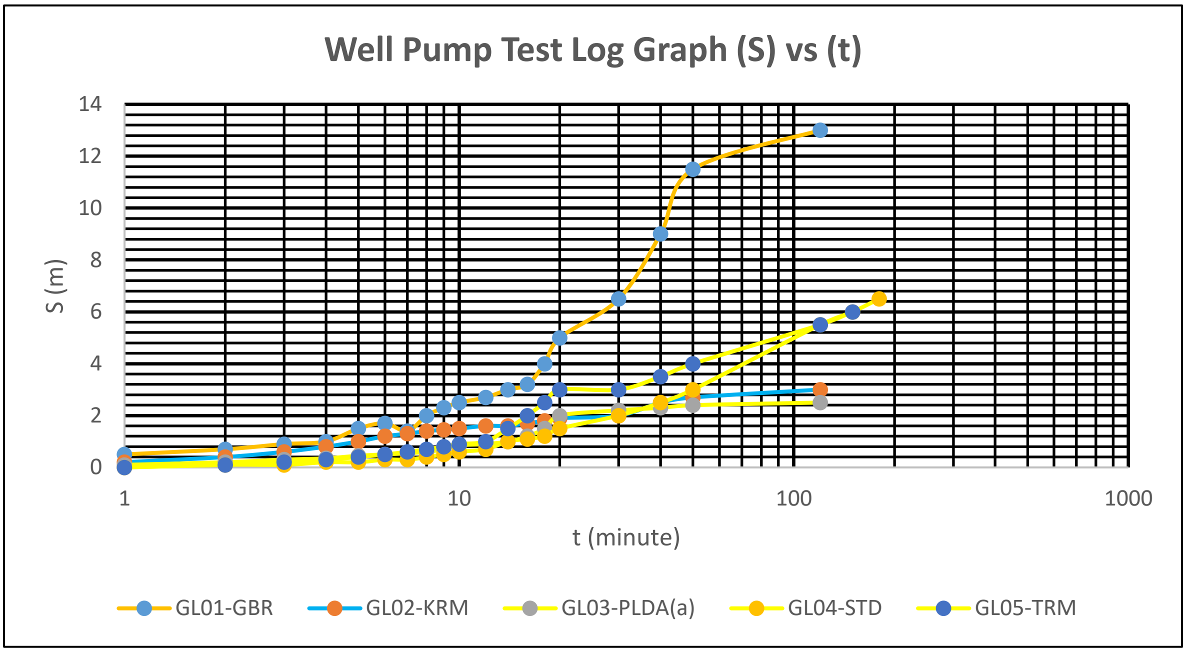


Figure 4: *Well pump test log graph*

Aquifer thickness determines the ability of the layer to pass water which groundwater potential will be higher in a thicker aquifer. The thickness of the shallow aquifer with a value of a weight of 1 indicates that the thickness of the aquifer is less than 6m (white). The weight value of 2 indicates ranges of aquifer thickness between 6m and 15m (light blue). The weight value 3 indicates a thickness between 16m to 25m (dark blue; Figure 5). The thickness for deep aquifers with a weight value of 2 indicates a thickness aquifer between 6m and 15m (light blue; Figure 6), a weight value of 3 which indicated by an area with dark blue has a thickness between 16m and 25m.

Water Quality Analysis

Assessment of water quality were measured from 5 wells in the study area (Table 4). Based on Water Quality Reference of the Minister of Health Regulation No 32 of 2017 regarding concerning Environmental Health Quality Standards and as contained in water for Sanitary Hygiene Purposes. Sanitary personal needs include bathing and brushing teeth, as well as for washing food, tableware, and clothing, and raw water for drinking water

There are 4 wells that meet all the requirements, they are GL-01GBR, GL-02KRM, GL-04STD and GL-05TRM (Table 5). Water quality assessment is carried out at the laboratory of West Sulawesi Provincial Health Office. From 5 measured wells, only well GL03-PLDA(a) chemical parameter that does not meet the requirements is Manganese with a yield of 1.33 mg/L. In PERMENKES No. 32 of 2017 the maximum value for Manganese is set at 0.5 mg/L. However, high Manganese (Mn) content can be reduced by using the method oxidation or can use the filtration method with filter media.

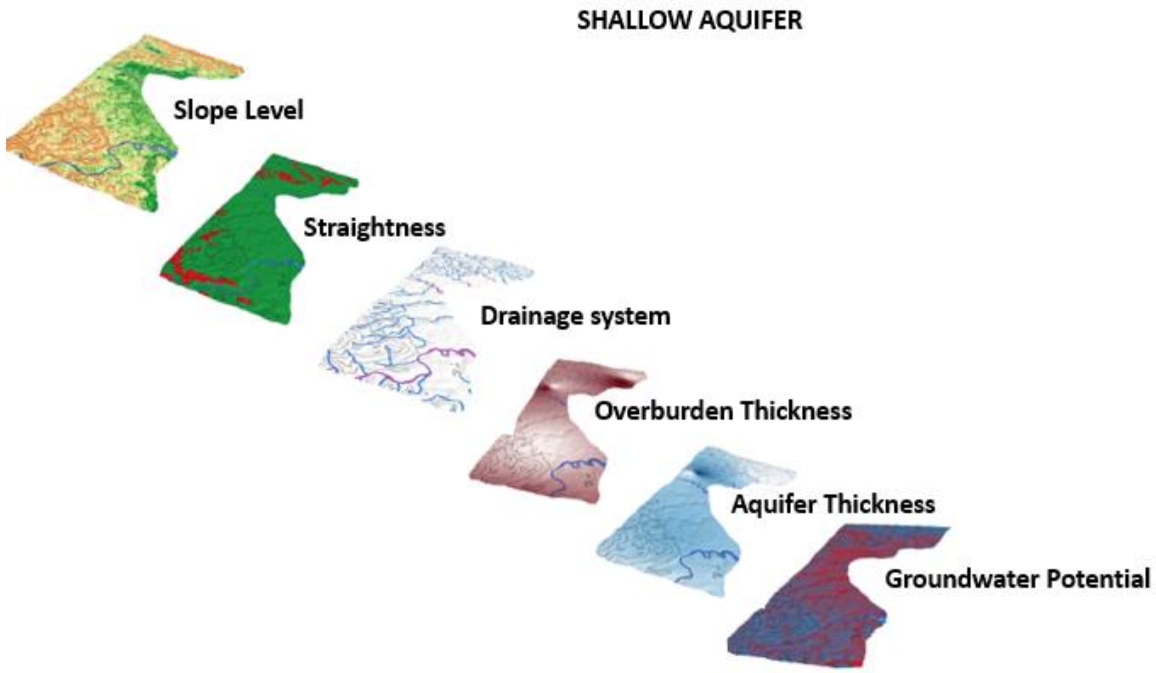


Figure 5: *Integrated groundwater potential parameters for the shallow aquifer*

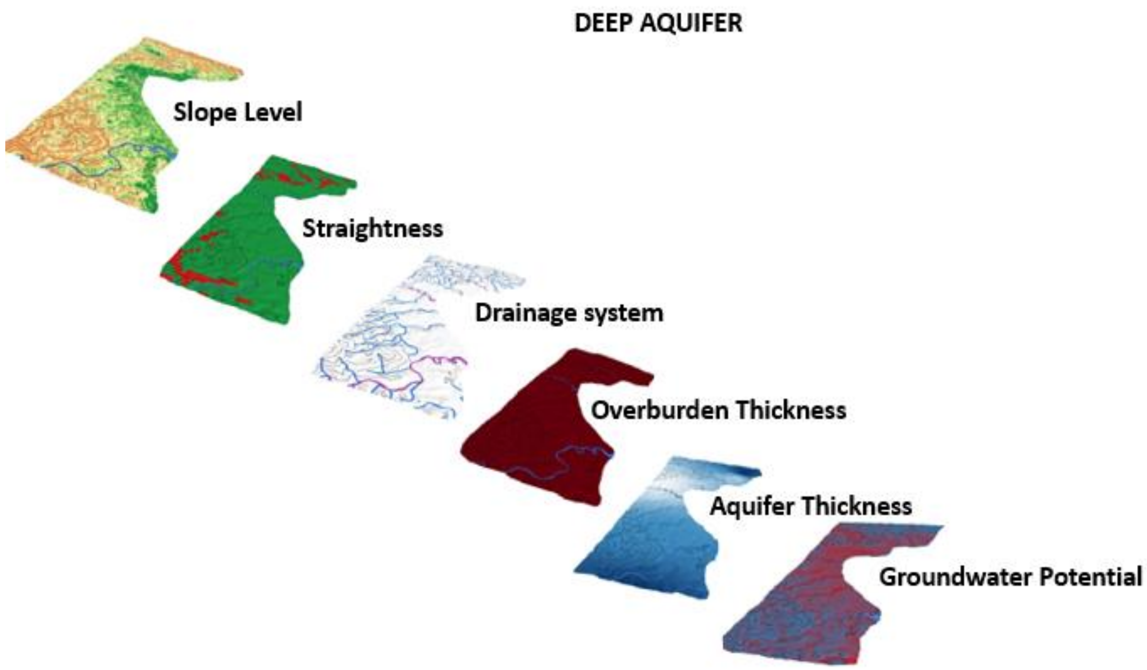


Figure 6: *Integrated groundwater potential parameters for the deep aquifer*

Table 4. The results of water quality analysis

No	Parameter	Result				
		Well-01GBR	Well-02KRM	Well-03PLD(a)	Well 04-STD	Well GL-05TRM
A	**Physical properties**					
1	Smell	No Smell	No Smell	No Smell	No Smell	No Smell
2	Flavour	No Flavour	No Flavour	No Flavour	No Flavour	No Flavour
3	Color	No Color	No Color	No Color	No Color	No Color
4	Temperature (°C)	21/22	21/22	21/22	21/22	21/22
5	TDS	57 mg/L	57 mg/L	131 mg/L	71 mg/L	89 mg/L
	Result	**Qualify**	**Qualify**	**Qualify**	**Qualify**	**Qualify**
B	**Chemical properties**					
1	PH	7.1	7.1	7.7	8.0	7.5
2	Chloride (Cl)	6.0 mg/L	6.0 mg/L	6.8 mg/L	5.4 mg/L	7.8 mg/L
3	Iron (Fe)	0.05 mg/L	0.05 mg/L	-	-	0.05 mg/L
4	Ammonium (NH_4)	-	-	-	-	-
5	Manganese (Mn)	0.28 mg/L	0.28 mg/L	1.33 mg/L	0.25 mg/L	-
6	$CaCO_3$	250 mg/L	250 mg/L	138 mg/L	330 mg/L	377 mg/L
7	Nitrite (NO_2-N)	-	-	-	-	-
8	Nitrate (NO_3-N)	-	-	-	-	-
	Result	**Qualify**	**Qualify**	**Not Qualify**	**Qualify**	**Qualify**

Table 5. Summary of the population and settlement coverage

No	Districts	Well Code	Well Debit (L/s)	Debit Availability (L/day)	Water Needs (L/people/day)	Assumption of 1 Family (people/house)	Amount Coverage (people)	Residential Coverage (House)
1	Simboro	GL-01GBR	0.3	25920	80	4	324	270
2		GL-02KRM	7.5	648000	80	4	8100	729
3		GL-05TRM	3	252900	80	4	3240	810
						TOTAL	**11664**	**2916**
4	Mamuju	GL-03PLD(a)	1	86400	80	4	1080	270
5		GL-04 STD	4	233280	80	4	2916	729
						TOTAL	**3996**	**999**

DISCUSSION

Water resources, Population & Settlement

GL01-GBR and GL02-KRM wells are situated in Mamuju District with population of around 3996 people and 999 settlements (Central of Statistics of Mamuju Regency, 2020; Table 6). GL04-STD and GL05-TRM wells in Simboro District to cover around 11664 people and 2916 settlements.

The overlay between the groundwater potential parameters shows the area of medium to good water potential in the shallow aquifer at (Figure 7) and good to very good groundwater potential at (Figure 8) deep aquifer. The coverage area of shallow aquifer (Figure 7) and deep aquifer (Figure 8) for GL01-GBR

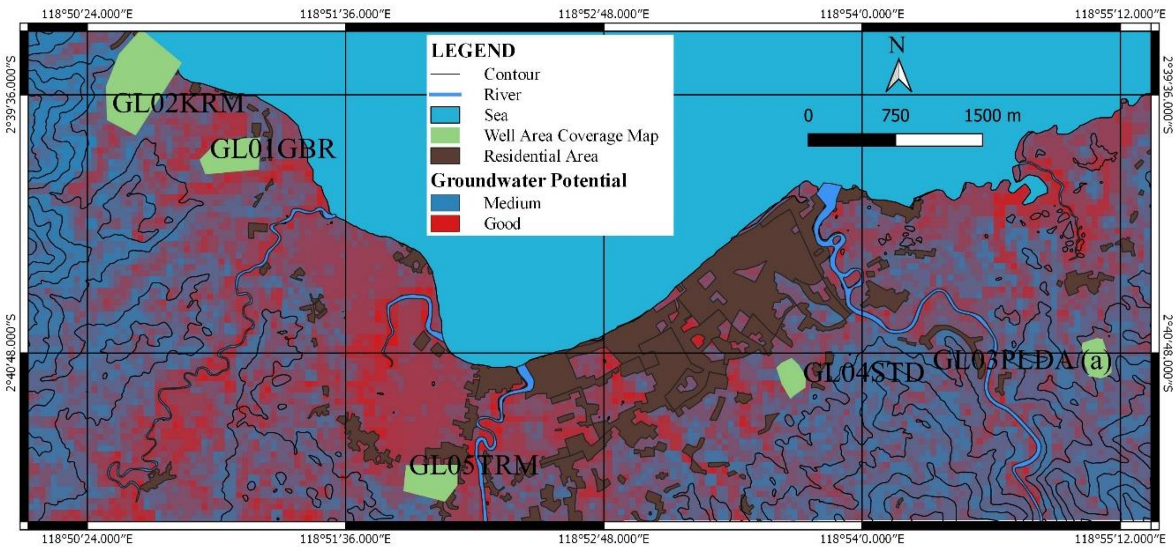


Figure 7: *Groundwater potential map of the shallow aquifer*

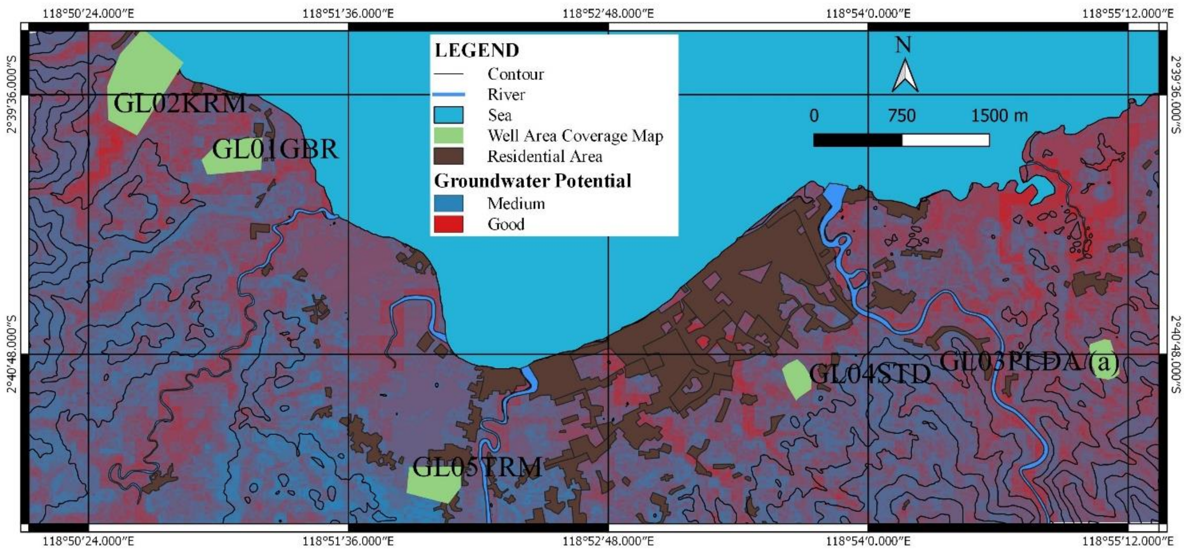


Figure 8: *Groundwater potential map of the deep aquifer*

well is about 130 m^2 and can provide water needs for 324 people/day or 81 houses. The coverage area for GL 02-KRM well is about 1320 m^2 and can provide water needs for 8100 people/day or 2025 houses. The coverage area for GL 03-PLDA (a) well is about 67 m^2 can provide water needs for 1080 people/day or 270 houses. The coverage area for GL 04-STD well is about 445 m^2 and can provide water needs for 2916 people/day or 729 houses. The coverage area for GL 05-TRM well is about 618 m^2 can provide water needs for 3240 people/day or 810 houses.

Water Distribution

The shared water flow direction and well distribution system from the water tank to the water storage container via distribution pipes are suggested based on:

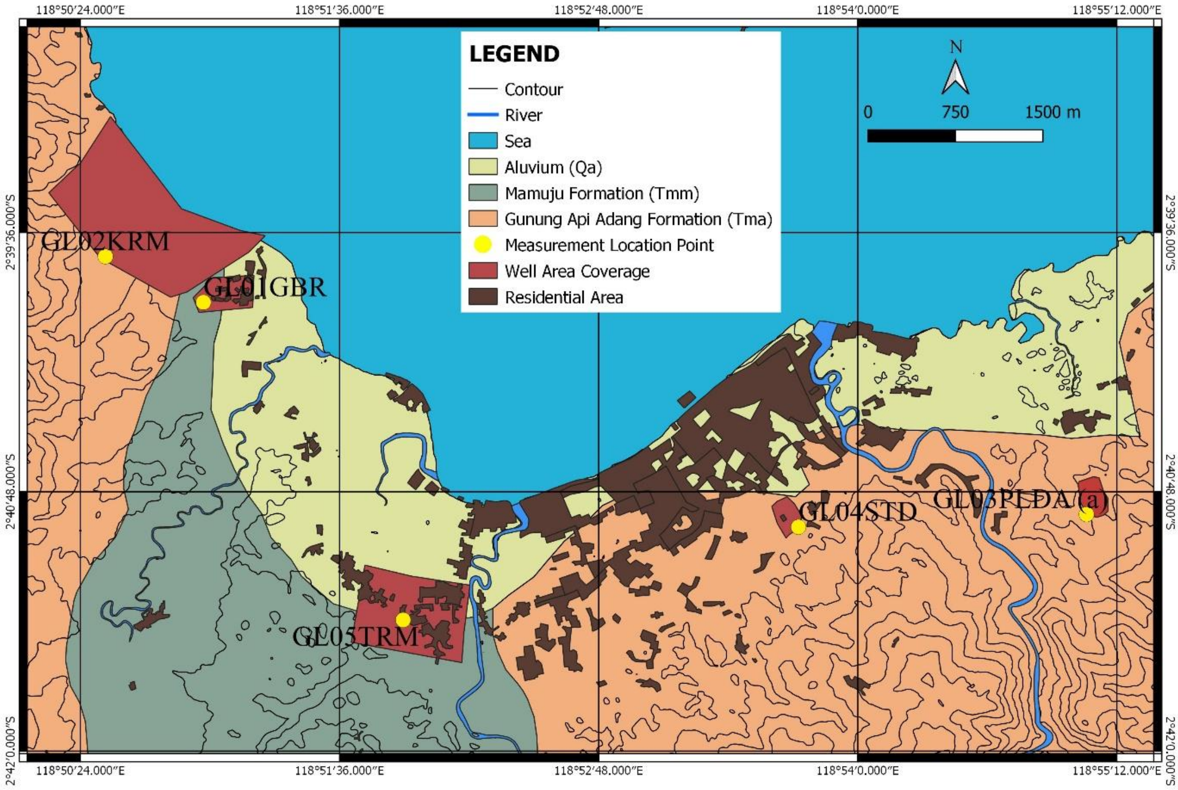


Figure 9: *An integrated map showing well coverage and residential areas on top of the geological map of the study area.*

a. Well distribution direction:

- Wells GL01-GBR, GL02-KRM, GL03-PLDA(a) and GL05-TRM have NE-SW direction
- Well GL04STD has SW-NE direction.

b. Well flow distribution system (Figure 10):

- Wells GL03-PLDA(a) and GL04STD can take advantage of gravity because the area has a slope elevation that can provide water pressure to make water flow.
- Wells GL01-GBR, GL02-KRM, and GL05-TRM can use a pumping distribution system because the area has a low elevation so that the pressure needs to be pushed to make the water flow.

CONCLUSIONS

a. Based on the resistivity values of geoelectrical data, the lithologies of the aquifer (Figure 9) are:

- Limestone and sandstone of the Mamuju Formation in wells GL01-GBR and GL05-TRM. Lapili rocks of the Gunung Api Adang Formation at well GL02-KRM.
- Breccia of the Gunung Api Adang Formation at wells GL03- PLDA(a), GL03- PLDA(b) and GL04-STD.
- Sandstone is located of the Alluvium Deposit in well GL06-BWS.

b. Aquifer type (shallow aquifer & deep aquifer)

- GL01-GBR; the depth of the shallow aquifer ranges from 13.97m to 19.16m and the depth of the deep aquifer ranges from 51.06m to 68.4m.
- GL02-KRM; the depth of the shallow aquifer ranges from 6.54m to 8.44m and the depth of the deep aquifer ranges from 94.05m to 132.6m.
- GL03PLDA(a); the depth of the shallow aquifer ranges from 17.63m to 19.2m and depth of the deep aquifer ranges from 67.78m to 105.9m.
- GL03PLDA(b) only has shallow aquifer that ranges from 75.57m to 100m.
- GL04-STD; the depth of the shallow aquifer ranges from 5.803m to 18.47m and deep aquifer has depth ranges from 60.33m to 85.47m.
- GL05-TRM; the depth of the shallow aquifer ranges from 13.71m to 19.1m and the depth of the deep aquifer ranges from 60.04m to 74.66m.
- GL06-BWS; the depth of the shallow aquifer ranges from 3.26m to 12.28m and the depth of the deep aquifer ranges from 26.93m to 40.02m.

c. Aquifer Types:

- Confined aquifer based on pump test data processing.
- Based on the depth of geoelectric drilling, it is divided into shallow aquifer with a depth of < 25m and deep aquifer > 25m.

d. Water Quality Analysis

- Wells GL01-GBR, GL02-KRM, GL04-STD and GL05-TRM meet the physical and chemical parameters as water for the requirements of the Minister of Health Regulation No 32 of 2017 concerning Environmental Health Quality Standards and as contained in water for Sanitary Hygiene Purposes.
- The water quality in well GL03-PLDA(a) meets the requirements of physical parameters but does not meet requirements of chemical parameters. The chemical parameter that does not meet the requirements is Manganese with a yield of 1.33 mg/L. In PERMENKES No. 32 of 2017 for Mangan the maximum value that is set at 0.5 mg/L Manganese (Mn).

e. Coverage of population who get groundwater potential:

- Wells GL01-GBR and GL02- KRM in Mamuju District can support around 3996 inhabitants or 999 settlements.
- Wells GL03-PLDA(a), GL04-STD and GL05-TRM in Simboro District can support around 11664 inhabitants or 2916 settlements.

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