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Hydrogeology and Groundwater Potential in The Sirimau District, Ambon City, Maluku Province

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ABSTRACT

The demand for clean water in Sirimau District is the highest among all districts in Ambon City, with a total of 14.6 million liters per day for 146,453 people. Moreover, the demand for clean water is increasing with population growth. Therefore, research on hydrogeology and groundwater potential is necessary. The study aims to analyze the discharge and quality of groundwater. The methods used include field surveys, geoelectric measurements, and the analysis of physical and chemical water parameters. The geology of Sirimau district can be divided into five units: Kanikeh Formation, Ultramafic Rock, Ambon Volcanic Rock, Coral Limestone, and Alluvium. Unconfined aquifers are identified in three geological units: the Ambon Volcanic Rock, Alluvium and Coral Limestone, while confined aquifers are in the Ultramafic Rock and the Kanikeh Formation. The water facies are calcium magnesium bicarbonate and sodium-potassium chloride sulfate facies. The groundwater flow in Sirimau District has a northwest flow direction with an average hydraulic gradient of 0.0104. The groundwater discharge in the unconfined aquifer of the Ambon Volcanic Rock is 30 l/s, which is classified as a large discharge. The water quality from physical parameters does not exceed the maximum limit except for three sampling points. In contrast, the chemical content mostly does not exceed the maximum limit except at one drilled well location. Three springs develop due to fractures, while another occurs due to contact.

Keywords: Sirimau District, Aquifers, groundwater, hydrogeology, physics-chemistry

INTRODUCTION

Water is essential for life and vital for humans' daily needs. However, population growth increases the demand for clean water while the availability of natural water resources is relatively dynamic [1]. This condition requires good quality water that can meet the population's needs. Even though water is abundant in nature, the availability of water that meets human needs is only 0.62% [2]. One source of clean water used by humans is groundwater.

Ambon Island has a large population concentrated in Ambon City. Sirimau District, the most populated area in Ambon City, has 146,453 people [3]. Assuming a clean water requirement of 100 liters per person per day [4], the water demand for this district is approximately 14.6 million liters per day. This water demand will increase with the population growth rate [5], while the groundwater resources in Ambon City are limited. Moreover, land use and climate change also pose a threat to water resources in Ambon City [6].

The issue of clean water in Ambon City is limited groundwater due to its proximity to the ocean, which is worsened by excessive extraction, which can degrade groundwater quality [7], [8]. The limited aquifer system, coupled with the amount of rainwater that can be accommodated, along with population growth and increasing groundwater extraction, can potentially cause significant water issues in the future [9], including in Ambon City.

Therefore, research on hydrogeology and groundwater potential, both in discharge and quality, is necessary to improve the use and management of groundwater and springs in the area and ensure they remain sustainable. This research can assist and provide insight into managing groundwater and springs in Ambon City.

METHODOLOGY

This research began with collecting secondary data, including topographic, hydrogeological, and geological maps. It was followed by a field survey to observe rock outcrops, determine rock types, and identify the distribution of dug wells, drilled wells, and springs.

Vertical Electrical Sounding (VES) was conducted using the Wenner configuration to determine resistivity values, with the data acquisition conducted via a geoelectric device (resistivity meter). Rock resistivity values were measured at five (5) locations and then processed using licensed IPI2Win and Surfer software. Next, the rock resistivity values are classified based on Table 1. The classification results are subsurface profiles, which will then be correlated using licensed Surfer and CorelDraw software to draw a hydrostratigraphic cross-section.

Table 1. Material Resistivity Value [10]

Material	**Resistivity (Ωm)**
Pyrite	0.01–100
Quartz	500–800,000
Calcite	1×10^{12}–1×10^{13}
Halite	30–1×10^{13}
Granite	200–100,000
Andesite	1.7×10^{2}–45×10^{4}
Basalt	200–100,000
Limestone	500–10,000
Shale	20–2,000
Sand	1–1,000
Clay	1–100
Groundwater	0.5–300
Seawater	0.2
Magnetite	0.01–1,000
Alluvium	10–800
Gravel	100–600
Conglomerate	2×10^{3}–10^{4}

Water facies were evaluated by cation and anion analysis. The results of measuring the chemical content of Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3, CO_3^{2-}, Cl^{-} and SO_4^{2-} are processed by converting units from mg/l to meq/l and calculating the CBE value. The calculated CBE value is relatively small, indicating that the data is valid and can be analyzed. The results are plotted on a Piper diagram to identify that the groundwater originates from water-rock interaction processes with local lithology.

Groundwater level data were collected from dug wells by measuring groundwater depth and well elevation. The groundwater table elevation was then calculated by subtracting the groundwater depth from the well elevation. A groundwater elevation contour map was generated using Geographic Information System (GIS) software by interpolating groundwater elevation data points. This map was then used to determine groundwater flow patterns, where flow direction is inferred from the slope of the water table. The hydraulic gradient value (i) is determined using the formula [11] based on the groundwater flow map.

$$i = \Delta h / L \quad (1)$$

where i = Hydraulic gradient; Δh = Difference in Groundwater level (m); and L = Distance between measurement points (m).

Groundwater discharge is determined by calculating flow rates, focusing exclusively on unconfined aquifers within the Ambon Volcanic Rock unit. The calculation is based on Darcy's Law, as represented by the following equation [12]:

$$Q = K \times i \times A \quad (2)$$

where Q = Water discharge (m^3/s or l/s); K = Hydraulic conductivity (m/s); i = Hydraulic gradient; and A = Cross-sectional area (m^2).

The quality of groundwater is assessed through physical and chemical measurements of water samples. Nineteen (19) samples were collected: 8 from dug wells, 4 from drilled wells, 4 from springs, and 3 from river water. Physical measurements included determining pH, Total Dissolved Solids (TDS), and Electrical Conductivity (EC) values.

Chemical measurements on NO_2^-, NO_3^-, Mn^+, Fe^{3+}, Cl^- and SO_4^{2-} [13] were conducted in all water samples. Water samples are then tested at the Maluku Province Health Laboratory Center (BLK). The water quality evaluation is according to the drinking water guideline in the Regulation of the Minister of Health of the Republic of Indonesia Number 2 of 2023. The quality classification is carried out based on Tables 2 to 5. Maps present the classification result for physical measurements, and tables are for chemical measurements.

Table 2. Classification of pH values [14]

pH	Classification
<3	Strong acid
3–6	Weak acid
7	Neutral
8-11	Weak alkali
>11	Strong alkali
6.5–8.5	Maximum level permitted in drinking water

Table 3. TDS classification [14]

Class	TDS	Category
1	0–1.000	Drinking water
2	1,000–1,500	Clean water
3	>1,500	Polluted water

Table 4. EC Classification [15]

EC (μS/cm)	Water Quality
<250	Very good
250–750	Good
750–2.000	Intermediate
2,000–3,000	Bad
≥ 3,000	Very bad

Table 5. Chemical Parameters Determining Groundwater Quality for Clean Water [16]

Element	Maximum Levels Allowed (mg/l)
Fe^{3+}	0.3
Mn^+	0.1
Cl^-	500
SO_4^{2-}	250
NO_3^-	50
NO_2^-	3

RESULTS AND DISCUSSIONS

Geology and Hydrogeology

The geology of the research area is composed of Kanikeh Formation, Ultramafic Rock, Ambon Volcanic Rock, Coral Limestone, and Alluvium [17] (Figure 1). Kanikeh Formation (TRJk) is the oldest rock formation, composed of alternating sandstone, shale, and siltstone with the intercalation of conglomerate and limestone. This formation is deposited during the Triassic to Jurassic. The Ultramafic Rock (JKu), composed of harzburgite, dunite, serpentinite, and gabbro, was unconformably deposited above the Kanikeh Formation during the Jurassic to Cretaceous time. The Ambon Volcanic Rock (Tpav) was formed from the late Pliocene to the early Pleistocene. The volcanic rock comprises andesite, dacite, breccia, and tuff. The Coral Limestone (Ql) and Alluvial (Qa) were deposited in the Pleistocene and Holocene. The rocks' properties can potentially form groundwater systems in this area.

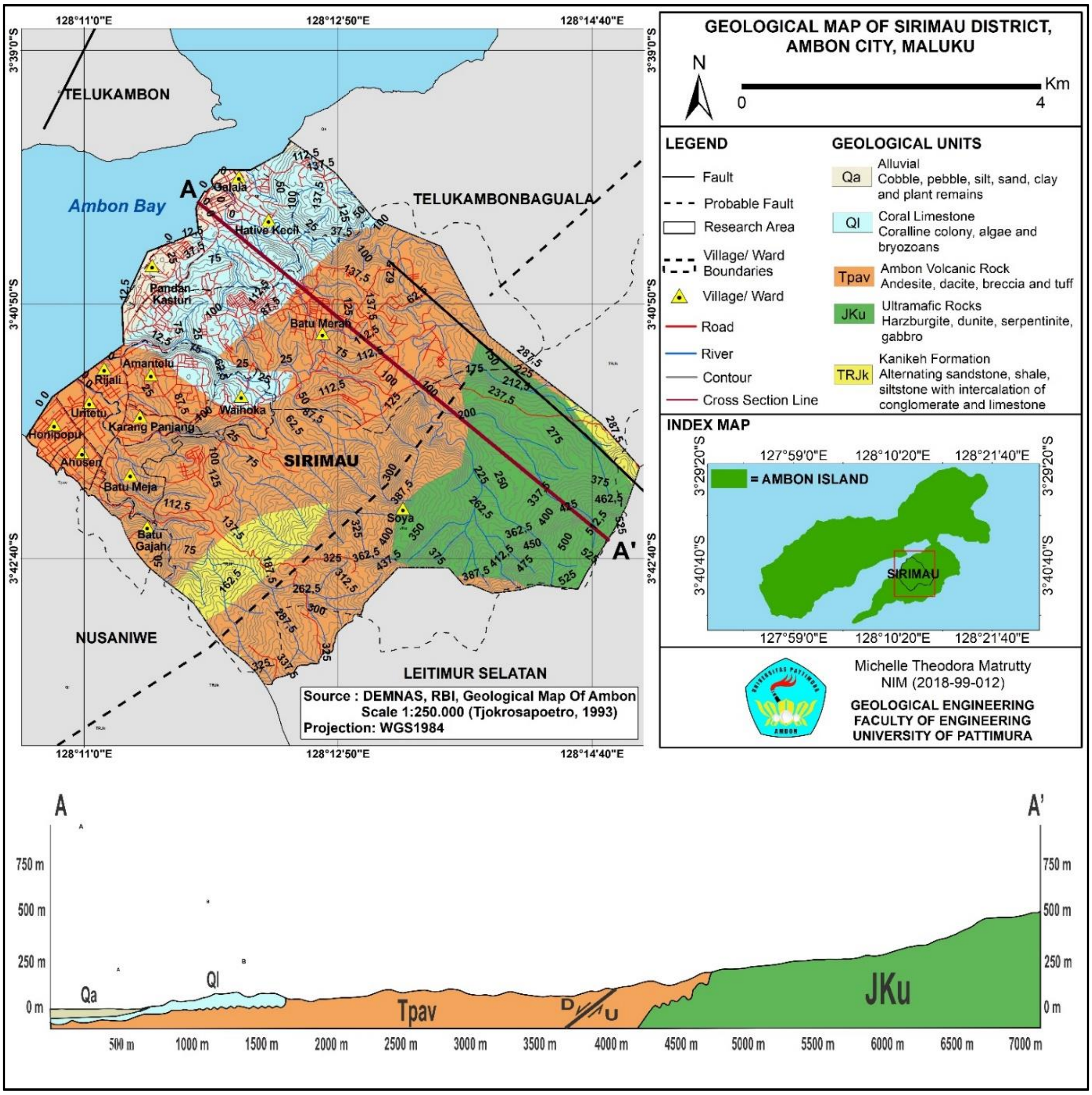

Figure 1. Geological Map of Sirimau District, Ambon City, Maluku [10]

The existence of aquifer and aquiclude rocks could characterize the groundwater system. The unconfined aquifers are identified in the Ambon Volcanic Rock, Coral

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Limestone, and Alluvium. The confined aquifers are distributed in the Ultramafic Rock and Kanikeh Formation. In addition, the Ultramafic Rock and Kanikeh Formation are also aquicludes. The hydrogeological system divides the study area into regions without exploitable groundwater, highly to moderately productive aquifers, and locally productive aquifers [18] (Figure 2).

The hydrostratigraphic cross-section at GL-3 to GL-4 locations (Figure 3) shows that the unconfined aquifer is in the sand, distributed from the surface to 5.6 meters below sea level. Limestone aquifer occurs at a depth of 0.82–2.07 meters. Based on the physical characteristics, the tuff layer, acting as an aquiclude, is detected at a depth of 4.98–9.14 meters. In the southeastern part, there is also a breccia layer from a depth of 7.01–9.72 meters, a confined aquifer with a tuff layer above it. There is also a sand layer from a depth of 4.32–28.83 meters, a confined aquifer with a tuff layer above it.

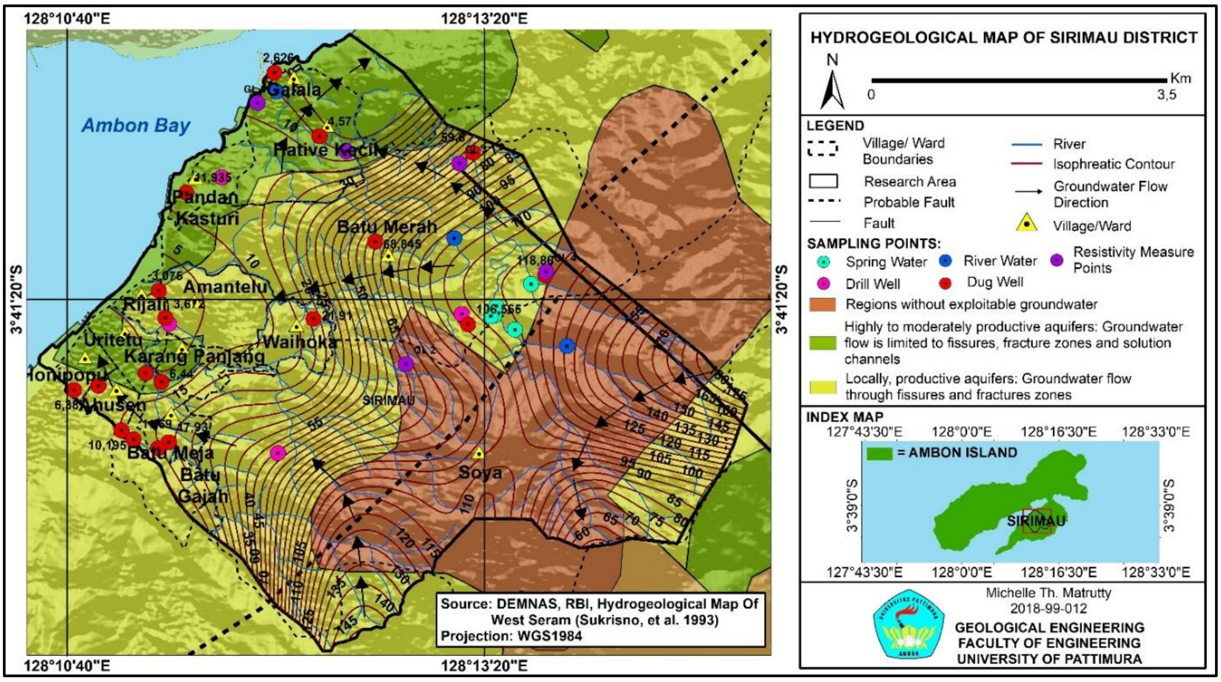

Figure 2. Hydrogeological Map of Sirimau District

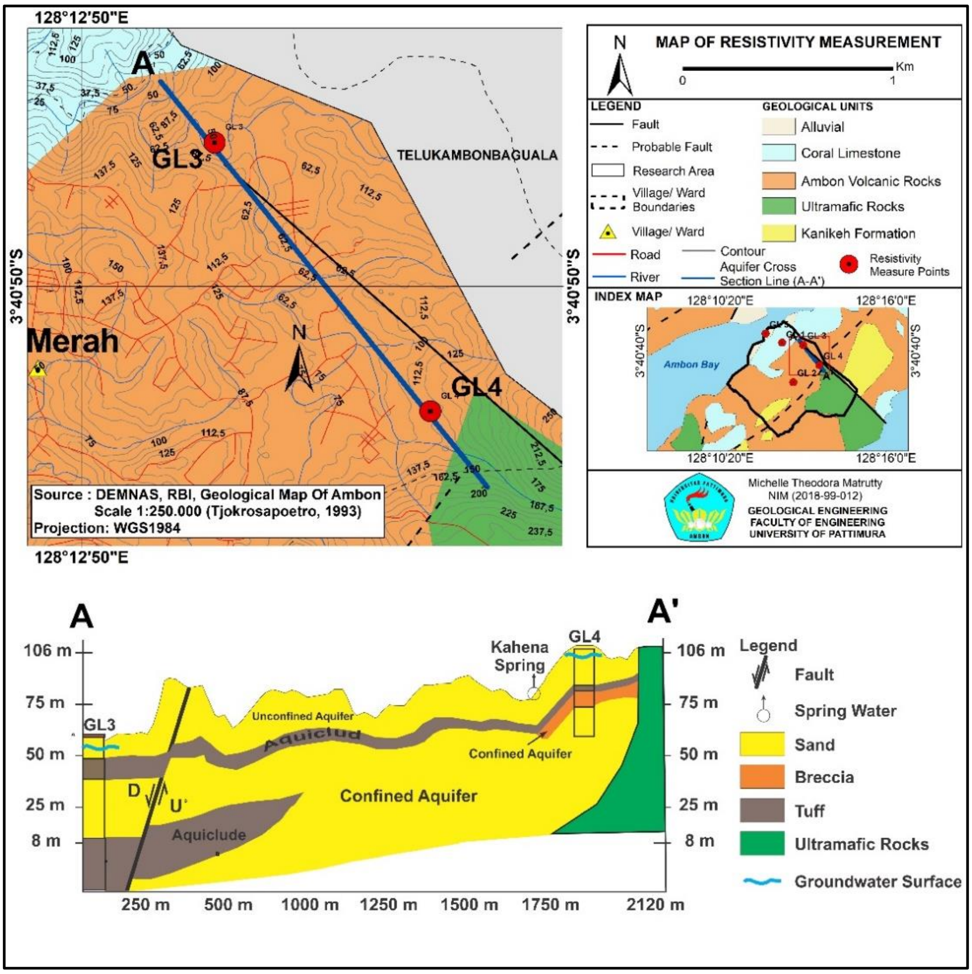

Figure 3. Hydrostratigraphic Section GL3 and GL4

Groundwater Facies

The chemical content analysis in the Piper diagram shows that groundwater, springs, and river water are grouped into calcium magnesium bicarbonate ($Ca^{2+}Mg^{+}HCO_3^{-}$) facies (Figure 4). They have similar facies with rainwater. It is suspected that the water in wells, springs and rivers is influenced by rainwater. Besides the magnesium bicarbonate facies, only one location in the river shows a different facies. The river is part of the Wae Ruhu watershed, classified into sodium-potassium chloride sulfate ($Na^{+}K^{+}Cl^{-}SO_4^{2-}$) facies.

The magnesium bicarbonate facies reflect magnesium input into the groundwater system, sourced either from the dissolution of magnesium-bearing rocks accompanied by bicarbonate ions (HCO_3^{-}), which originate from the dissolution of carbonate minerals in limestone [19]. Bicarbonate ions indicate that the water comes from shallow and young groundwater, which suggests that surface conditions influence the hydrogeology in the Sirimau District. The calcium magnesium bicarbonate facies can be associated with carbonate rocks, showing a chemical composition of water that is rich in calcium (Ca^{2+}) and magnesium (Mg^{2+}) along with bicarbonate ions (HCO_3^{-}).

The geological condition related to this facies is the presence of limestone. Apart from that, the calcium magnesium bicarbonate facies can also be caused by rainwater that has accumulated and interacted with volcanic rocks rich in magnesium (Mg^{2+}).

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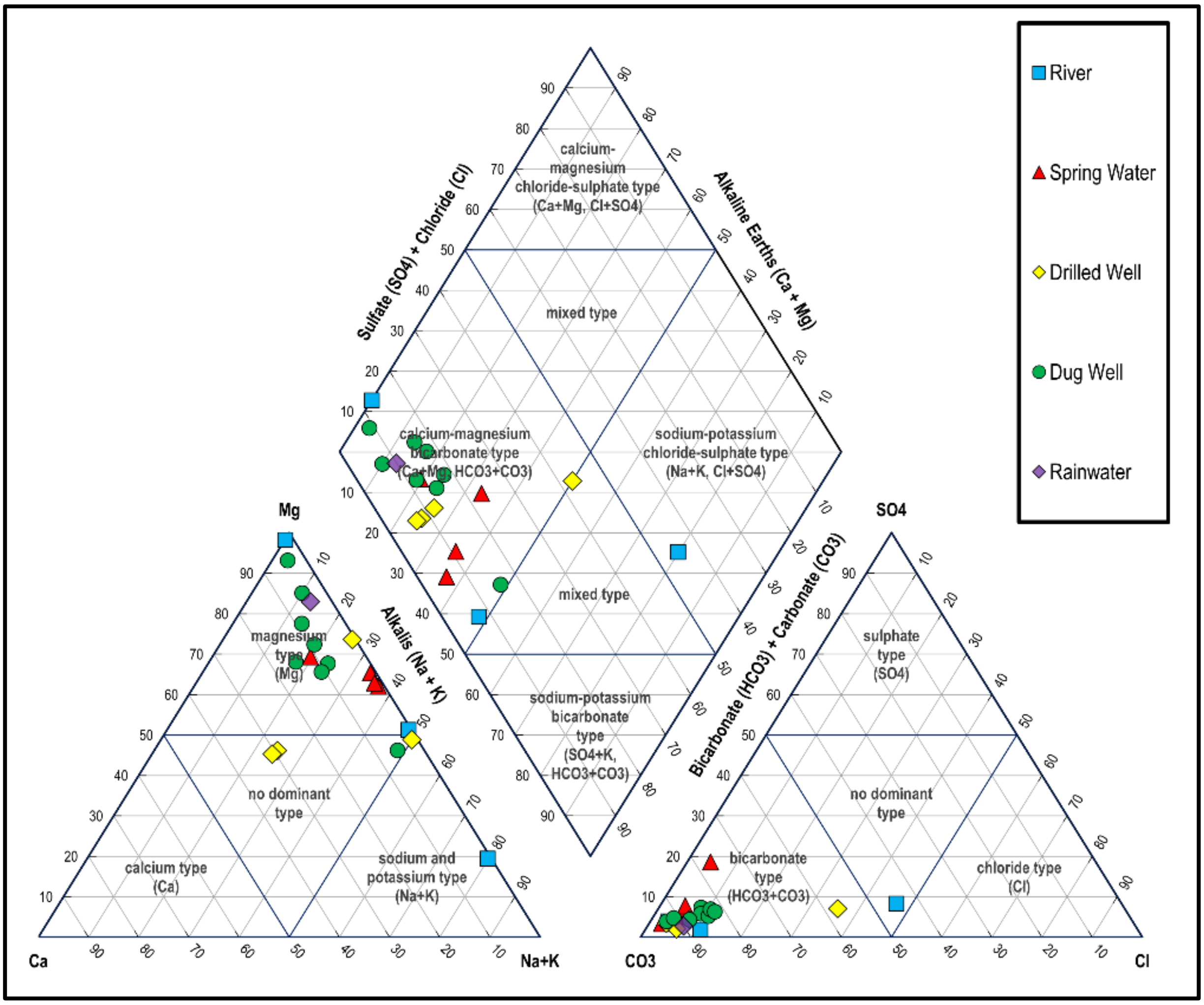

Figure 4. Piper Diagram in the study area

Groundwater Discharge

The groundwater flow direction in the area flows from the southeast to the northwest (Figure 5). This area's topography controls these flows. The hydraulic gradient in the three cross-sectional areas was calculated based on groundwater flow patterns. The hydraulic gradient values are 0.0022, 0.0216, and 0.0075, with an average hydraulic gradient in the Sirimau District of 0.0104.

Groundwater discharge calculation is only in the Ambon Volcanic Rock aquifer. The hydraulic gradient value (i) is obtained as 0.0022, and the hydraulic conductivity value (k) at the measurement point is 0.00023 m/s. The area of the aquifer is based on hydrostratigraphic cross-section is 59142.63 m^2. By using the equation (2), the amount of groundwater discharge in the unconfined aquifer in the Ambon Volcanic Rock is 0.030 m^3/s (30 l/s or 2,592,000 l/day), which is classified as large discharge based on the Decree of the Minister of Energy and Mineral Resources of the Republic of Indonesia Number 1451/10 /MEM/2000.

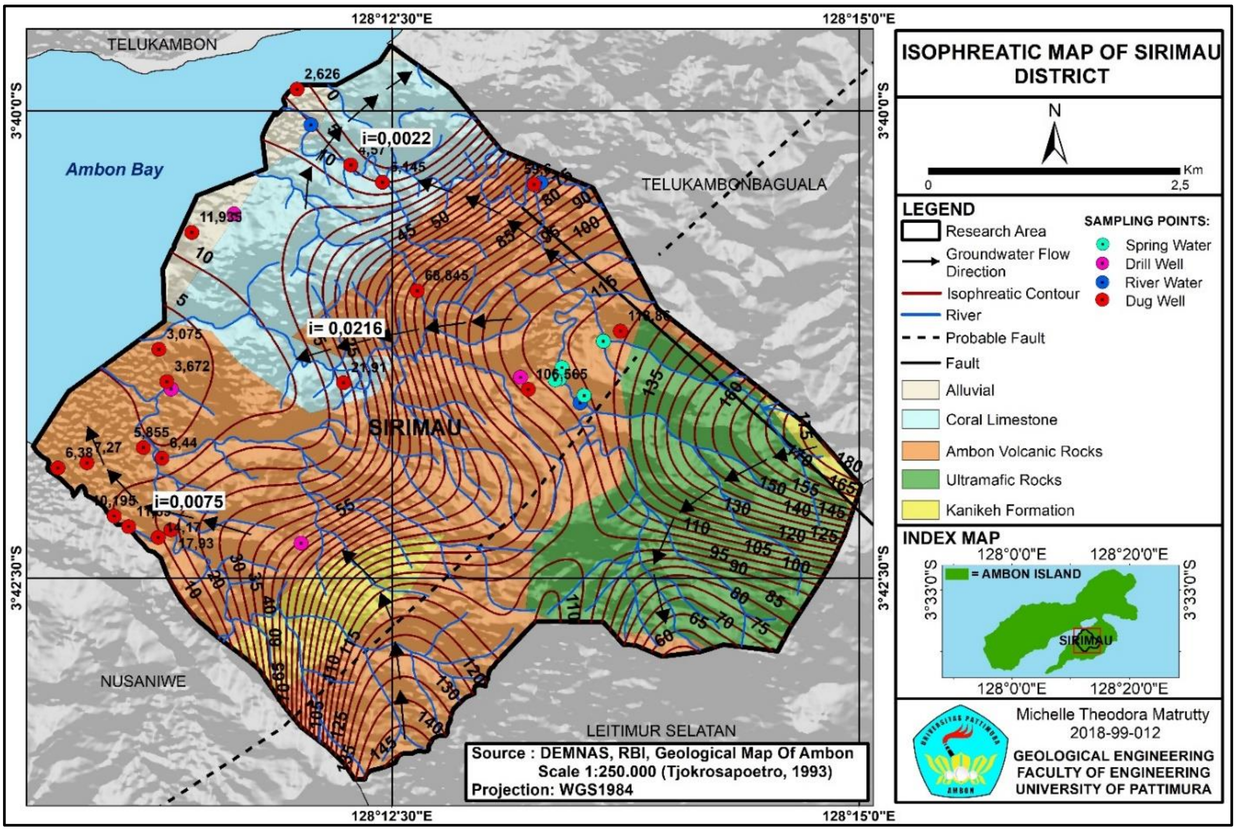

Figure 5. Isophreatic Map of Sirimau District

Groundwater Quality

Groundwater quality is distinguished from the pH, TDS, and EC values. The pH values of water samples in the research area are classified into pH 3–6 (weak acid) and 6.5–8.5 (drinkable), as seen in Figure 6. The drinkable water is marked with green dots, while yellow dots are water with weak acidic properties. The drinkable location is distributed widely in the area, mostly in the Ambon volcanic rocks but less in the Coral Limestone and Alluvium. Meanwhile, the lower pH values (weak acids) are observed in three locations. They are distributed in the Coral Limestone and Alluvium. These differences occurred because of the interaction between meteoric water and volcanic rocks. The rainwater and waste from surrounding communities have also influenced the conditions.

The distribution of TDS values of water samples in the research area ranged below 500 ppm, marked with green dots on the map (Figure 7). The concentration of ions dissolved in the water influences the TDS value in water. Several factors, such as the reaction of groundwater with the aquifer or the reaction with the seawater, can affect the concentration of ions dissolved in water. However, the TDS value in all dug wells in the research area does not exceed the limit determined by the Regulation of the Minister of Health of the Republic of Indonesia Number 2 of 2023.

The EC values distribution in the area results in a varied number, which is classified into very good, good, and moderate (Figure 8). Very good water is marked with dark green dots, light green dots indicate good water quality, while yellow dots show moderate water quality. Water samples near the sea have higher value variations than those far from the

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sea. The EC value increases if salt ions are present [20]. Apart from that, several factors that influence the EC value are topography and lithology, which comprise the aquifer. High EC values indicate the interaction of groundwater with the seawater.

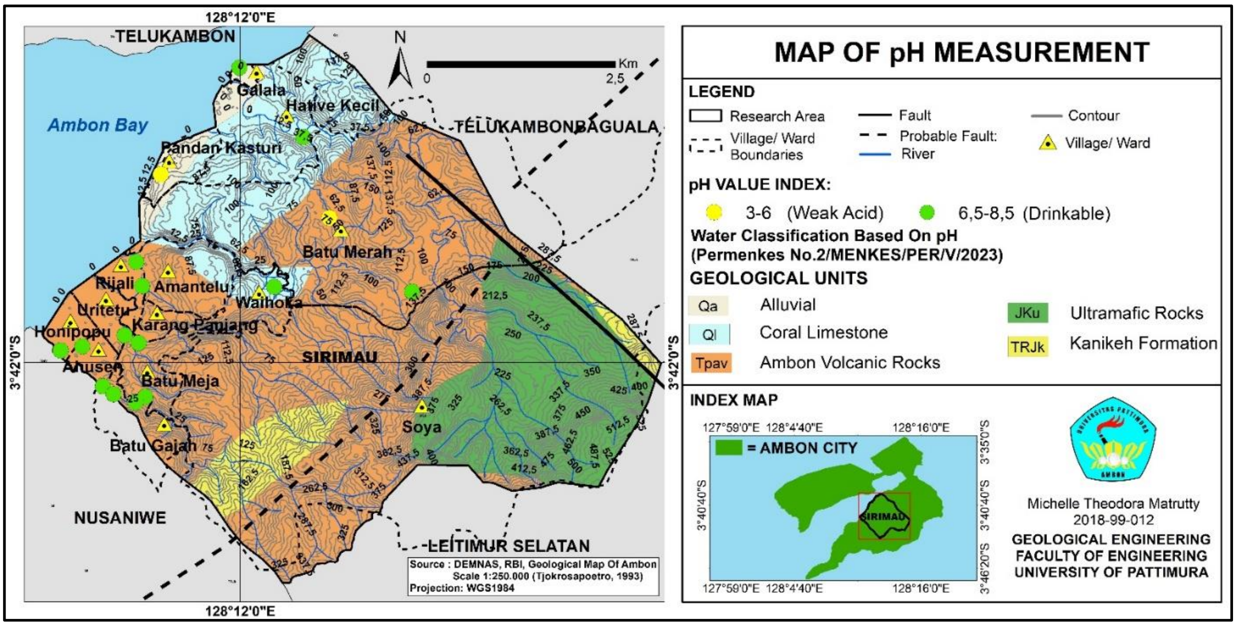

Figure 6. Map of pH Measurement

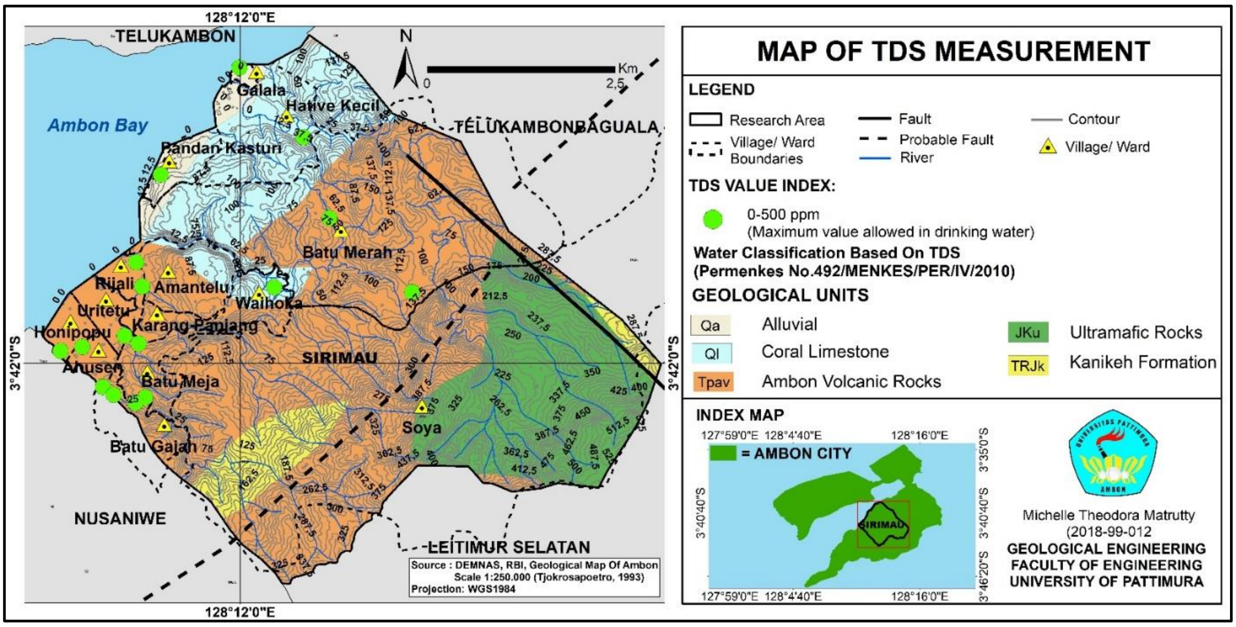

Figure 7. Map of TDS Measurement

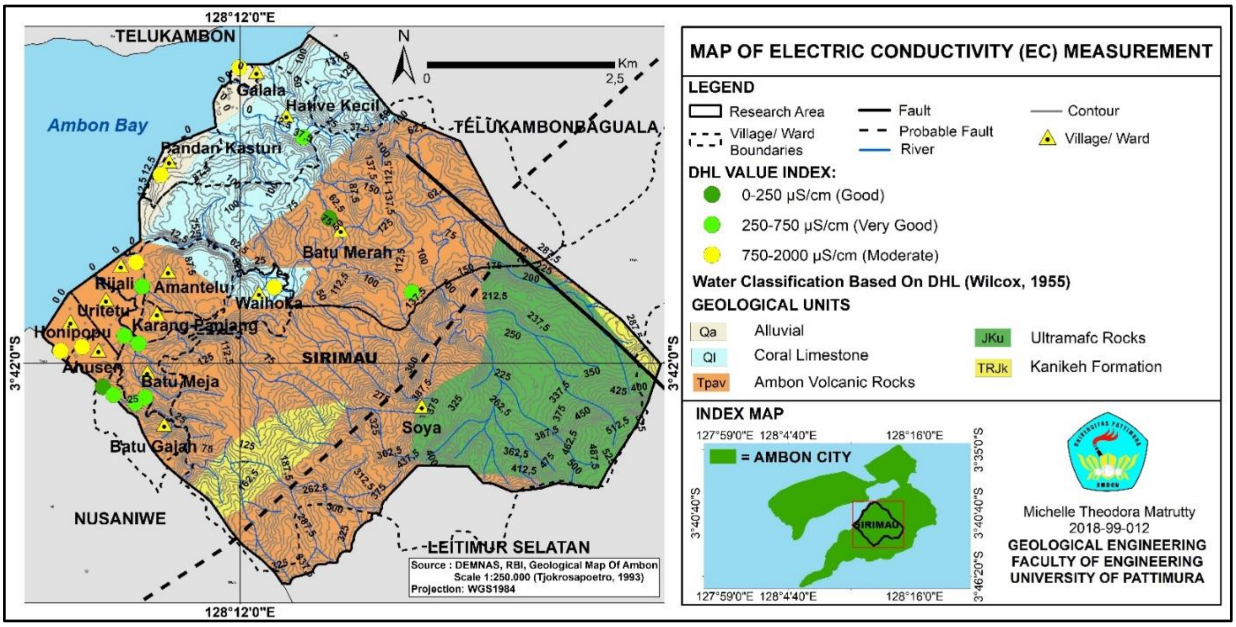

Figure 8. Map of Electric Conductivity (EC) Measurement

Water quality results analysis showed that all samples did not exceed the maximum levels permitted for hygiene standards based on the regulation, except for the Mn content in the SB Belso sample, whose value is above the maximum allowed level. At that point, water should not be used or consumed because it can have a negative impact on health (Table 6).

Table 6. Chemical Parameter Test Results

Sample Origin	Coordinate		Element Concentration (mg/l)					
	Latitude	Longitude	NO_2	NO_3	Mn	Fe	Cl	SO_4
AS Hulu	3°41'33.83"S	128°13'30.53"E	0	0	0.0031	0.002	20.4	4.75
AS Tengah	3°40'23.15"S	128°13'17.92"E	0	0	0.0007	0.0014	7.39	11.49
AS Hilir	3°40'4.53"S	128°12'4.08"E	0.01	0	0.0012	0.0029	184.5	44.81
SB Kapaha	3°40'33.12"S	128°11'39.35"	0.25	0.23	0.0001	0.0023	191.1	50.61
SB Belso	3°41'29.32"S	128°11'19.19"	0	0	0.1122	0.0044	18.7	8.83
SB Soya	3°41'25.57"S	128°13'11.41"E	0	0	0.0006	0.0065	4.68	6.47
SB Kayu Tiga	3°42'18.85"S	128°12'0.92"E	0	0	0.0004	0.0078	13.3	10.51
SG Waihoka	3°41'27.38"S	128°12'14.55"E	0.03	0.02	0.0004	0.006	26.6	31.84
SG Hative Kecil	3°40'22.97"S	128°12'27.05"E	0	0	0.0008	0.0067	7.88	13.43
SG Batu Gajah	3°42'14.66"S	128°11'19.07"E	0	0	0.0018	0.007	8.13	12.47
SG Ahusen	3°41'53.01"S	128°10'52.08"E	0.03	0.02	0.0409	0.0085	28.5	25.16
SG Rijali	3°41'16.64"S	128°11'15.26"E	0	0	0.0068	0.0074	30.3	20
SG Galala	3°39'53.13"S	128°11'59.61"E	1.09	0.87	0.0063	0.0081	21.4	19.51
SG Batu Merah	3°40'57.79"S	128°12'38.25"E	0.01	0	0.0092	0.0101	11.5	9.06
SG Uritetu	3°41'48.18"S	128°11'10.27"E	0	0	0.0071	0.0082	22.9	17.22
Air Hujan	3°41'37.10"S	128°11'27.13"E	0.01	0	0	0.004	11.3	5.33

Spring Water

The research area comprises four springs: Kahena, Es, Intake, and Panas Baru, all within the Ambon Volcanic Rock. Among these, the Es, Panas Baru, and Intake springs are located near a normal fault that intersects the Ambon Volcanic Rock. Their proximity to this geological structure classifies them as fracture-type springs influenced by fault activity. In contrast, the Kahena spring is a contact-type spring formed at the boundary between the Ultramafic Rock and the Ambon Volcanic Rock, as depicted in Figure 9. Based on observations and according to residents, Intake and Kahena Springs are continuously releasing water throughout the year (perennial), while the Es and Panas Baru are seasonal springs (intermittent).

The physical measurement results show that the four springs' EC, TDS, and pH values are good quality. The chemical test results also show that no content exceeds the maximum level permitted by the regulation.

Spring recharge was determined based on the groundwater flow pattern. The dominant groundwater flow is in the northwest direction, following topography. The spring recharge area is in the Soya Mountains, which are high elevation, and the discharge is in the Intake and Arbes springs (Figure 10).

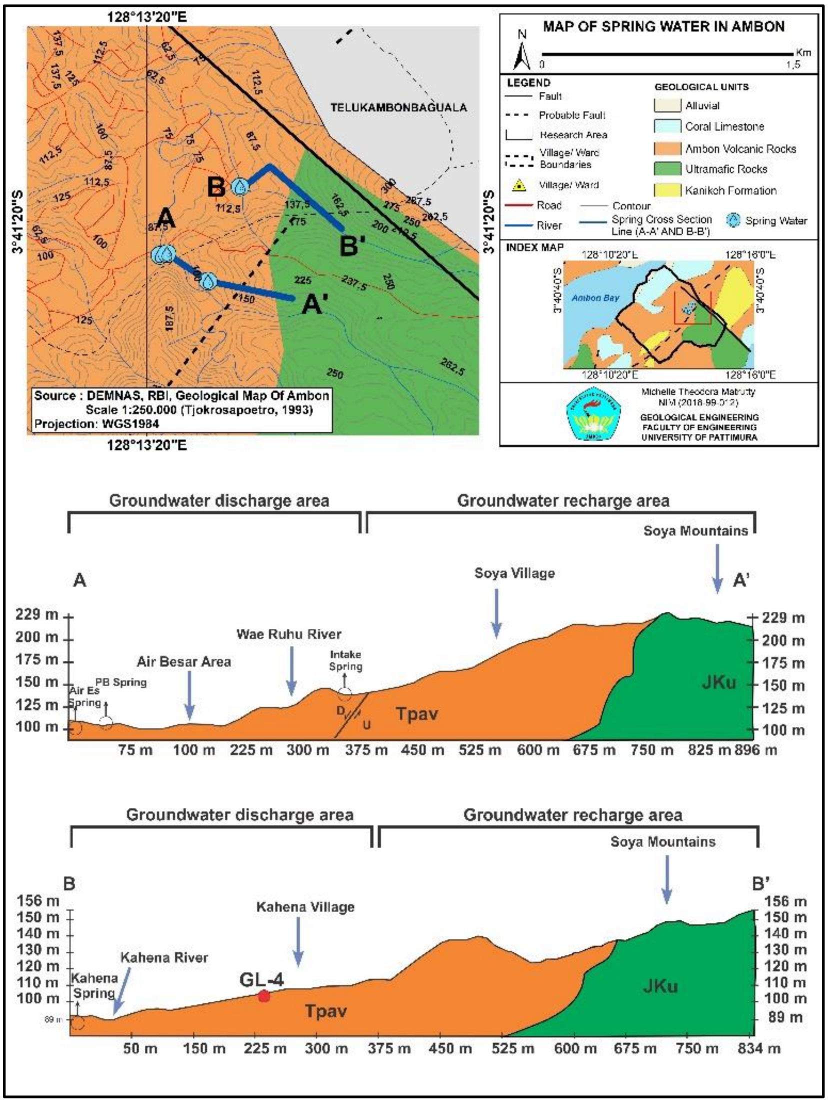

Figure 9. Cross-section of Arbes Springs and Kahena Springs

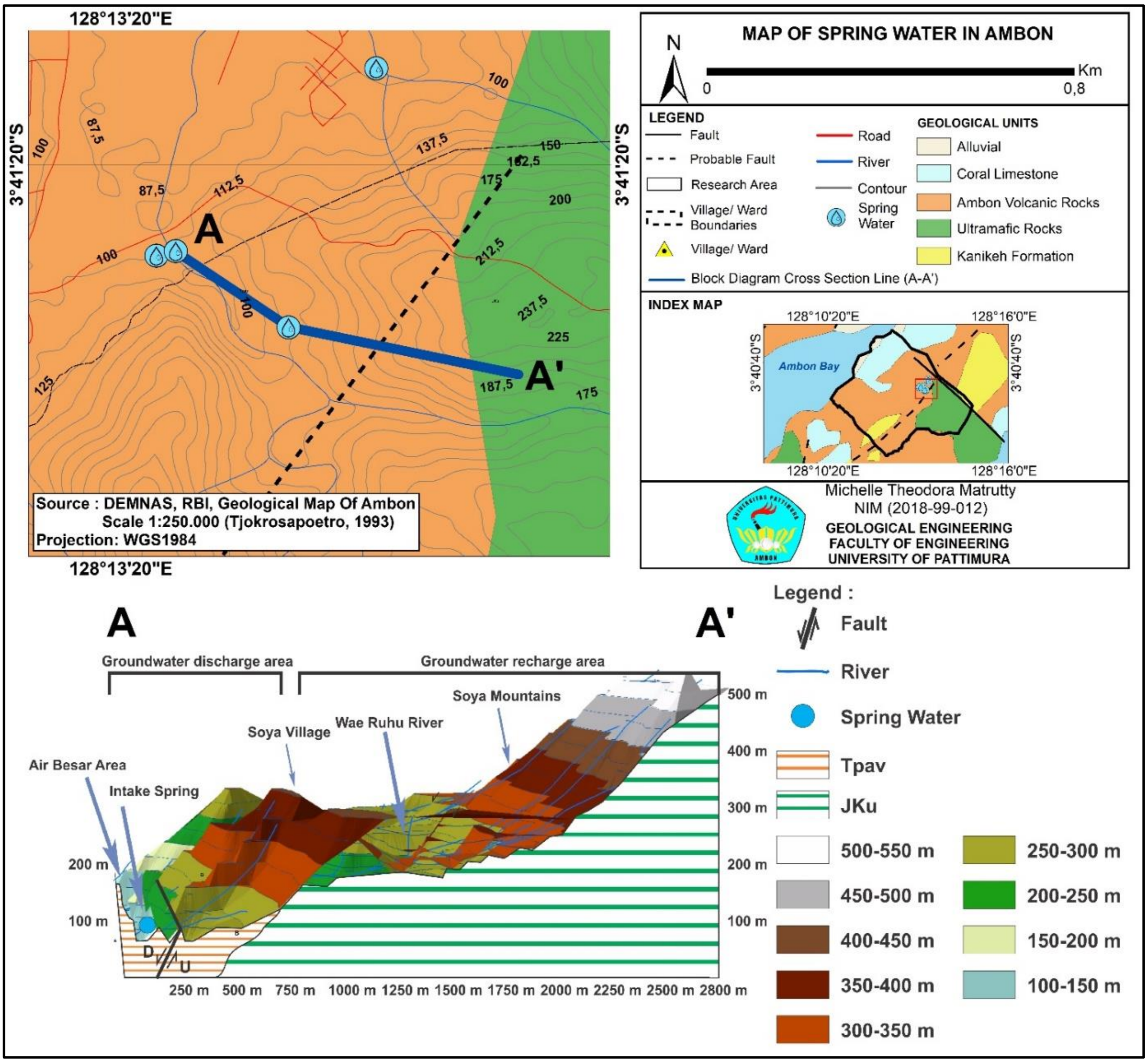

Figure 10. Springs Block Diagram

CONCLUSION

The Ambon Volcanic Rock, Coral Limestone, and Alluvium are unconfined and confined aquifers, while the Ultramafic Rock and Kanikeh Formation are aquicludes. All four (4) springs in Sirimau District are in the Ambon Volcano Rock. The types of springs are fracture and contact springs. The groundwater discharge was 0.030 m^3/s or 30 l/s or 2,592,000 l/day, classified as a large discharge. The water facies of unconfined aquifer groundwater, confined aquifer groundwater, river and spring water is calcium magnesium bicarbonate. The river water facies in the downstream part of the Wae Ruhu watershed have sodium-potassium chloride-sulfate. Both springs and groundwater share similarities with rainwater, which indicates the possibility of rainwater being the main supplier of Sirimau District aquifers. Drinking water quality is classified as good based on its physical properties. The chemical test shows that the contents did not exceed the specified limits, except for 1 drilled well location. The water quality in the spring is considered good, following the regulation's chemical and physical parameter limits.

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