Determination of groundwater recharge area using environmental isotopes and hydrochemical data in Raimanuk area, East Nusa Tenggara

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Abstract, The Raimanuk area, located in East Nusa Tenggara, had a population growth rate of 0.94% in 2019. The area used for harvested agricultural land was 205 Ha. As the population and agricultural land increase, the water demand also increases. Groundwater extraction is feared to be out of control because Raimanuk is a drought-prone area. The availability of groundwater is closely related to the amount of water infiltration and the amount taken. In accordance to that, it is necessary to find out the origin of groundwater in the Raimanuk area. This study aimed to determine the groundwater recharge area using environmental isotopes analysis of 2H and 18O and hydrochemistry. Rainwater samples were taken in March and April 2021 once in every month at 4 locations with different elevations. Groundwater sampling was carried out at 10 drilled wells, 6 dug wells, and 4 springs. Groundwater in the Raimanuk area can be grouped into 4 groups. The groundwater recharge area is in the Mandeu hills at an altitude above 390 masl. The composition of groundwater is dominated by calcium (Ca), sodium-potassium (NaK), and bicarbonate (HCO3).

1. Introduction

Raimanuk is one of the areas in the province of East Nusa Tenggara. The Raimanuk area is located in Raimanuk District, West Tasifeto District, Nanaet Duabesi District, North Biboki District, Biboki Tanpah District, and Laen Manen District. In 2019, the population in the Raimanuk area was 80,264 people, and the average population growth rate was 0.94% [1-3]. Most of the people in the Raimanuk area work as farmers with an agricultural harvest area of 205 hectares in 2019 [1-3]. Therefore, the need for water is increasing, so that the government and the community begin to use groundwater. It is feared that groundwater utilization will become uncontrolled due to dry surface water and low rainfall. This is supported by the inclusion of the Raimanuk area as one of the drought-prone areas [4]. Groundwater is a renewable natural resource, but if it is not managed correctly and pays attention to the balance between recharge and extraction, its potential availability will decrease [5]. Therefore, determining the groundwater recharge area is one of the keys to sustainable groundwater use in the Raimanuk area.

One method that is often used to determine groundwater recharge areas is environmental isotopes and hydrochemical data [6-10]. In this study, the environmental isotopes used were deuterium (2H) and oxygen-18 (18O). The concentration of isotopes in the hydrological system is influenced by air temperature, rainfall, land, and altitude [7-8]. In addition, the chemical composition of groundwater is
used to determine the origin of the groundwater. This is done by knowing the groundwater and water-rock interaction type in the aquifer, such as cation and anion exchange reactions [9].

2. Location

The research was conducted in the Raimanuk area, which consists of Mandeu hills in the east and Aroki plains in the west, located between UTM coordinates (WGS 1984) Zone 51S lines 694936 – 713239 m 8963437 – 8975645 m (figure 1). Based on field observations, the geological conditions of the study area consist of calcareous siltstone unit, part of the Bisane Formation, which is pre-Permian [11], has a white-brown color, with a layered structure, silt grain size, good sorting, closed packaging, the composition of siliciclastic and carbonate materials [27]. The crystalline limestone unit, part of the Maubisse Formation, Permian to Triassic in age [11]. The formation has a fresh white color, weathered blackish white color, massive structure, sand grain size, good sorting, closed packaging, and bioclastic and carbonate material composition [27]. The calcareous pebble siltstone unit, part of the Bobonaro Complex, which is Tertiary in age [11]. The formation has a white-brown, red, black, greenish-white color, with a layered or laminated structure, silt grain size, good sorting, closed packaging, composition of siliciclastics, carbonate, and iron oxide minerals [27].

![Geologic map of Raimanuk and surrounding areas](image)

**Figure 1.** Geologic map of Raimanuk and surrounding areas [28]

The basalt porphyry lava unit, part of the Maubisse Formation, but is interpreted as a fragment of the Triassic-Tertiary Bobonaro Complex [11], has fresh gray-brown color and weathered brown color, with a massive structure, porphyrofanitic texture, phenocryst size 0.5-2 mm, base mass <0.5 mm, composition in the form of plagioclase and mafic minerals [27]. The coraline limestone unit, part of the Noele Formation, which is Tertiary to Quaternary [11], has a whitish brown color, with a layered structure, the grain size of sand to gravel, poor sorting, open packaging, the composition of bioclastic and carbonate material [27]. The wackestone unit, part of the Quaternary Coral Limestone [11], has a
fresh white-brown color, weathered color blackish brown, massive structure, fine sand to silt size, good sorting, closed packaging, carbonate material composition [27]. Alluvium formed during the Holocene [11], has a brown and white-brown color with a rounded to subrounded shape [27]. The size is dominated by sand and gravel, but there is also sedimentary material in gravel to lumps but in much less quantity.

3. Instrumentation and Sampling
Rainwater sampling was carried out at 4 different locations between an altitude of 300-800 masl in March and April 2021, which were taken once each month (figure 2). Rainwater samples were stored in two 150 ml glass bottles. In addition, groundwater sampling was carried out at 20 groundwater points consisting of 10 drilled wells taken in April 2021, 6 dug wells and 4 springs taken in June 2021. Groundwater samples were stored in two glass bottles of 150 ml size and one-piece 1000 ml plastic bottle. The naming of SB samples for drilled wells, SG for dug wells, and MA for springs, and the numbering of each sample is sorted from right to left (figure 2). Furthermore, all samples were tested at the Central Laboratory for Isotope and Radiation Applications, National Nuclear Energy Agency, Jakarta, to obtain stable isotope data ($^2$H and $^{18}$O) and groundwater hydrochemistry (major ion).

![Figure 2. Map of groundwater and rainwater sampling locations [28]](image)

4. Methodology
4.1. Major ion analysis
Laboratory analysis was carried out for cations in the form of Na$^+$, K$^+$, Ca$^{2+}$, Mg$^{2+}$ and anions in the form of HCO$_3^-$, SO$_4^{2-}$, Cl. The results of major ion testing in the laboratory use units of mg/L or ppm. Supposedly, the chemical analysis method uses meq/L or epm, therefore unit conversion is required before chemical analysis. Concentration with units of mg/L can be converted to units of meq/L by multiplying by the conversion factor (table 1), with the following equation [12]:

$$
\text{meq/L} = \frac{\text{mg/L}}{18.0154}$$
Before geochemical data can be used for analysis, it is needed to consider the calculation of reaction errors (RE). The RE value is expressed as a large percentage of the total number of ions. The unit used in calculating the RE value is meq/L. The reaction error is defined as a percentage of the total ion concentration. A positive RE value indicates an excess of cations, while a negative RE indicates an excess of anions [13]. The laboratory test analysis is repeated if the RE value has more than 10% [14]. The equation for calculating RE is as follows:

\[ RE = \frac{\Sigma \text{Cation} - \Sigma \text{Anion}}{\Sigma \text{Cation} + \Sigma \text{Anion}} \times 100\% \]  

4.2. Hydrogeochemical analysis

The type of rock determines the chemical content of groundwater passed along the groundwater flow, for example basalt has Na\(^+\), Ca\(^{2+}\), Mg\(^{2+}\) as the main cations and HCO\(_3^-\) as the primary anion. Limestone has Ca\(^{2+}\) as the primary cation and HCO\(_3^-\) as the primary anion. Siltstone has Na\(^+\) as the primary cation and Cl\(^-\), SO\(_4^{2-}\) as the main anions [7]. In addition, groundwater with a dominance of HCO\(_3^-\) comes from shallow and young groundwater. The primary source of HCO\(_3^-\) is CO\(_2\) which is dissolved in rainwater and seeps into the soil [9]. Based on this process, the ions in the recharge area are Ca\(^{2+}\) and HCO\(_3^-\). In the deeper areas, the Na\(^+\) and Cl\(^-\) content increased [15].

Hydrogeochemical analysis was carried out using a trilinear piper diagram. The trilinear piper diagram is used as the basis for characterizing the chemical composition of groundwater to distinguish types and determine the dominant type of groundwater. The trilinear piper plot the percentage of cations and anions on a trilinear diagram, and the hydrochemical facies classification can be known based on the dominant ion [13]. This diagram consists of two triangles located on the right and bottom left, and above it is a parallelogram. The three buildings have a reading scale of 100. The triangle on the left is for cations consisting of Na\(^+\) + K\(^+\), Ca\(^{2+}\), and Mg\(^{2+}\). The triangle on the right consists of Cl\(^-\), SO\(_4^{2-}\), and HCO\(_3^-\) + CO\(_3^{2-}\). The two triangles are represented as units of % meq/L [16].

4.3. Isotope analysis

The value of the ratio for \(^{18}\text{O}\) and \(^{2}\text{H}\) in water molecules depends on altitude, rainfall, humidity, pressure, and temperature of the surrounding environment [7,17]. Groundwater located in adjacent locations that comes from places with different elevations will have different ratios. Groundwater from a higher elevation has a smaller ratio than the ratio of groundwater from a lower elevation. Furthermore, the higher the rainfall, the lower the ratio value to rainwater. Conversely, the smaller the rain, the richer the ratio value to rainwater. Based on this phenomenon, groundwater studies using isotopes as tracers need to consider the effect of elevation and rainfall on the values of \(^{18}\text{O}\) and \(^{2}\text{H}\). Considering that rainfall,
pressure, temperature, and humidity vary from time to time, the values of \(^{18}\text{O}\) and \(^{2}\text{H}\) at each rainwater sampling location must be averaged using equation [7]:

\[
\delta, \%	ext{oo} = \frac{\sum_{i=1}^{n} P_i \delta_i}{\sum_{i=1}^{n} P_i}
\]  

(3)

\(\delta\) is the mean isotopic ratio of the rainwater, \(\delta_i\) is the isotope ratio of the rainfall sample to \((i)\), \(P_i\) is the amount of rainfall between the \((i-1)\) and \((i)\) samples.

Next, it is crucial to determine a Local Meteoric Water Line (LMWL) to find sources of groundwater. Determination of groundwater recharge elevation using a chart comparing stable isotope values (\(\delta^{18}\text{O}\) and \(\delta^{2}\text{H}\)) with elevation (masl). The elevation of groundwater recharge can be calculated using the equation from the plot of the average stable isotope in the rain event against the elevation of the rainwater sampling location. Furthermore, the values of \(\delta^{18}\text{O}\) and \(\delta^{2}\text{H}\) in groundwater samples can be inputted into the equation to calculate the elevation of groundwater recharge.

5. Results and discussion

5.1. Groundwater hydrochemistry

As an initial step before carrying out the hydrogeochemical analysis, the primary ion units were converted from mg/L to meq/L and checked for reaction errors in laboratory results (table 2) [13]. The unit conversion uses equation 1 with the conversion factor in table 1, and the reaction error calculation uses equation 2. The results can be seen in table 3.

| Type of sample | Elevation (masl) | Na\(^+\) (mg/L) | K\(^+\) (mg/L) | Ca\(^{2+}\) (mg/L) | Mg\(^{2+}\) (mg/L) | Cl\(^-\) (mg/L) | SO\(_4^{2-}\) (mg/L) | HCO\(_3^{-}\) (mg/L) |
|---------------|-----------------|----------------|----------------|-----------------|-----------------|---------------|-----------------|------------------|
| SB-1          | 410.6           | 65.0           | 2.4            | 107.3           | 31.8            | 24.8          | 64.2            | 485.6            |
| SB-2          | 400.5           | 37.0           | 5.6            | 118.8           | 36.1            | 26.9          | 46.5            | 491.8            |
| SB-3          | 371.7           | 64.4           | 1.1            | 43.0            | 13.1            | 12.8          | 41.8            | 321.8            |
| SB-4          | 352.6           | 36.2           | 2.4            | 107.0           | 15.4            | 7.9           | 43.5            | 476.0            |
| SB-5          | 338.1           | 41.9           | 2.8            | 144.4           | 9.5             | 9.3           | 44.4            | 485.7            |
| SB-6          | 330.2           | 220.5          | 6.5            | 71.2            | 12.4            | 131.3         | 29.9            | 648.6            |
| SB-7          | 368.3           | 35.6           | 3.3            | 102.5           | 15.9            | 14.9          | 20.5            | 409.1            |
| SB-8          | 356.5           | 344.2          | 2.2            | 20.0            | 2.4             | 155.5         | 48.6            | 616.1            |
| SB-9          | 362.5           | 53.9           | 3.7            | 87.8            | 21.1            | 23.2          | 11.0            | 461.6            |
| SB-10         | 374.7           | 35.0           | 2.4            | 89.0            | 30.9            | 15.6          | 30.5            | 499.2            |
| SG-1          | 369.1           | 80.8           | 3.0            | 56.4            | 28.0            | 12.1          | 169.8           | 355.4            |
| SG-2          | 387.6           | 38.6           | 1.7            | 44.9            | 11.1            | 6.8           | 15.0            | 290.8            |
| SG-3          | 347.7           | 101.3          | 4.1            | 51.1            | 12.0            | 18.9          | 65.2            | 414.7            |
| SG-4          | 365.5           | 37.3           | 1.5            | 47.3            | 10.5            | 3.7           | 8.4             | 312.7            |
| SG-5          | 343.2           | 61.6           | 1.9            | 51.3            | 14.8            | 24.1          | 31.6            | 339.0            |
| SG-6          | 368.6           | 52.4           | 1.0            | 42.9            | 31.9            | 12.2          | 27.8            | 414.7            |
| MA-1          | 676.2           | 46.5           | 2.4            | 35.1            | 16.8            | 10.0          | 15.8            | 309.2            |
| MA-2          | 533.7           | 13.4           | 1.4            | 51.9            | 19.0            | 6.6           | 5.7             | 302.9            |
| MA-3          | 392.0           | 186.3          | 11.4           | 53.8            | 61.1            | 126.3         | 173.3           | 627.9            |
| MA-4          | 412.6           | 39.0           | 1.8            | 29.3            | 22.7            | 7.3           | 15.6            | 301.4            |
Table 3. Summary of major ion chemistry data in meq/L and calculation of reaction error

| Type of sample | Na⁺ (meq/L) | K⁺ (meq/L) | Ca²⁺ (meq/L) | Mg²⁺ (meq/L) | Cl⁻ (meq/L) | SO₄²⁻ (meq/L) | HCO₃⁻ (meq/L) | RE (%) |
|---------------|-------------|------------|--------------|--------------|-------------|---------------|---------------|--------|
| SB-1          | 2.8         | 0.1        | 5.4          | 2.6          | 0.7         | 1.3           | 8.0           | 4.1    |
| SB-2          | 1.6         | 0.1        | 5.9          | 3.0          | 0.8         | 1.0           | 8.1           | 4.2    |
| SB-3          | 2.8         | 0.0        | 2.1          | 1.1          | 0.4         | 0.9           | 5.3           | -3.6   |
| SB-4          | 1.6         | 0.1        | 5.3          | 1.3          | 0.2         | 0.9           | 7.8           | -4.0   |
| SB-5          | 1.8         | 0.1        | 7.2          | 0.8          | 0.3         | 0.9           | 8.0           | 3.8    |
| SB-6          | 9.6         | 0.2        | 3.6          | 1.0          | 3.7         | 0.6           | 10.6          | -2.1   |
| SB-7          | 1.5         | 0.1        | 5.1          | 1.3          | 0.4         | 0.4           | 6.7           | 3.2    |
| SB-8          | 15.0        | 0.1        | 1.0          | 0.2          | 4.4         | 1.0           | 10.1          | 2.3    |
| SB-9          | 2.3         | 0.1        | 4.4          | 1.7          | 0.7         | 0.2           | 7.6           | 0.6    |
| SB-10         | 1.5         | 0.1        | 4.4          | 2.5          | 0.4         | 0.6           | 8.2           | -3.9   |
| SG-1          | 3.5         | 0.1        | 2.8          | 2.3          | 0.3         | 3.5           | 5.8           | -5.4   |
| SG-2          | 1.7         | 0.0        | 2.2          | 0.9          | 0.2         | 0.3           | 4.8           | -4.0   |
| SG-3          | 4.4         | 0.1        | 2.5          | 1.0          | 0.5         | 1.4           | 6.8           | -3.9   |
| SG-4          | 1.6         | 0.0        | 2.4          | 0.9          | 0.1         | 0.2           | 5.1           | -5.1   |
| SG-5          | 2.7         | 0.0        | 2.6          | 1.2          | 0.7         | 0.7           | 5.6           | -3.0   |
| SG-6          | 2.3         | 0.0        | 2.1          | 2.6          | 0.3         | 0.6           | 6.8           | -4.4   |
| MA-1          | 2.0         | 0.1        | 1.7          | 1.4          | 0.3         | 0.3           | 5.1           | -4.3   |
| MA-2          | 0.6         | 0.0        | 2.6          | 1.6          | 0.2         | 0.1           | 5.0           | -5.0   |
| MA-3          | 8.1         | 0.3        | 2.7          | 5.0          | 3.6         | 3.6           | 10.3          | -4.0   |
| MA-4          | 1.7         | 0.0        | 1.5          | 1.9          | 0.2         | 0.3           | 4.9           | -3.8   |

The RE calculation results from 20 groundwater samples used in this research have an RE value of less than 10% so that all samples can be used for the next stage of analysis because they do not exceed the predetermined standard [14].

5.2. Groundwater facies

Based on the trilinear piper diagram presented in figure 3, of the 20 groundwater samples taken from drilled wells, dug wells, and springs, groundwater facies can be grouped into 3 types, namely CaHCO₃, NaKHCO₃, and no dominant type HCO₃⁻. The CaHCO₃ facies are located at SB-2, SB-4, SB-5, SB-7, SB-9, SB-10, MA-2 with alluvium and crystalline limestone lithology. The dominant Ca²⁺ content is due to the interaction with carbonated rocks. The presence of Ca²⁺ cations is influenced by weathering of rocks. The composition of HCO₃⁻ indicates that there is mixing with shallow groundwater as local recharge [9,22]. The chemical reaction that shows the weathering process of the CaHCO₃ facies mineral [8,18]:

\[
\text{CaCO}_3 + H_2O \leftrightarrow \text{Ca}^{2+} + \text{HCO}_3^- + \text{OH}^-
\]

The NaKHCO₃ facies is located at SB-6, SB-8, SG-3, MA-3 with alluvium and carbonate pebble siltstone lithology. The dominant Na⁺ and K⁺ content are due to the interaction with siliciclastic rock material. The presence of Na⁺ and K⁺ cations is influenced by weathering rocks and silicate minerals in the form of feldspar (Na-feldspar and K-feldspar) [26]. The content of HCO₃⁻ indicates that there is
mixing with shallow groundwater as local recharge [9,22]. The chemical reaction that shows the weathering process of the NaKHCO$_3$ facies mineral [8,18]:

$$2\text{NaAlSi}_3\text{O}_8 + 2\text{CO}_2 + 3\text{H}_2\text{O} \leftrightarrow 2\text{Na}^+ + 2\text{HCO}_3^- + 4\text{SiO}_2 + \text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4 \quad (5)$$

$$2\text{KAlSi}_3\text{O}_8 + 2\text{CO}_2 + 3\text{H}_2\text{O} \leftrightarrow 2\text{K}^+ + 2\text{HCO}_3^- + 4\text{SiO}_2 + \text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4 \quad (6)$$

Facies No dominant type HCO$_3$ is located at SB-1, SB-3, SG-1, SG-2, SG-4, SG-5, SG-6, MA-1, MA-4 within the alluvium, carbonate pebble siltstone, basalt porphyritic lava, and crystalline limestone. The content of cation elements in this group is not dominant, but its composition is still influenced by weathering of the rock through which it passes [23]. This is indicated by the presence of HCO$_3^-$ which is still dominant. Water with HCO$_3^-$ content generally comes from shallow groundwater and young groundwater types [22]. The primary source of HCO$_3^-$ ions in groundwater is CO$_2$ dissolved in rainwater that enters the soil and dissolves more CO$_2$. Thus, HCO$_3^-$ dominates the groundwater facies. The water changes by dissolving CO$_2$ with minerals in the rocks it passes, releasing HCO$_3^-$ [19]. The three groups of groundwater-dominated by HCO$_3^-$ are included in the type of freshwater that has not been contaminated [25]. Groundwater in all sampling points comes from its original groundwater source.

![Figure 3. Piper Trilinier diagram of the groundwater samples](image)

5.3. Stable isotope and recharge area identification

The analysis of the recharge area using stable isotopes requires 3 types of isotopic charts, namely the Local Meteoric Water Line (LMWL) chart, the $\delta^{18}$O depletion chart for elevation, and the $\delta^2$H depletion chart for elevation [7,8]. Stable isotope data obtained from the laboratory were averaged using equation
3 (table 4) and plotted into the Raimanuk Meteoric Water Line (RMWL) chart. From the chart, the RMWL equation is obtained as follows:

$$\delta^2H = 8.1257 \delta^{18}O + 11.195$$  \hspace{1cm} (7)

**Table 4.** Rainwater $\delta^{18}O$ and $\delta^2H$ isotope analysis

| Type of sample | Elevations (masl) | March Rainfall (mm) | $\delta^{18}O$ (%) | $\delta^2H$ (%) | April Rainfall (mm) | $\delta^{18}O$ (%) | $\delta^2H$ (%) | Mean isotope ratio |
|---------------|------------------|---------------------|-------------------|----------------|---------------------|-------------------|-----------------|------------------|
| TH-01         | 746.2            | 252                 | -7.43             | -47.40         | 263.5               | -7.12             | -47.20          | -7.27            | -47.30           |
| TH-02         | 667.7            | 252                 | -6.72             | -45.60         | 263.5               | -6.84             | -43.80          | -6.78            | -44.68           |
| TH-03         | 416.6            | 252                 | -5.01             | -30.90         | 263.5               | -6.39             | -40.50          | -5.72            | -35.81           |
| TH-04         | 352.1            | 252                 | -4.89             | -30.80         | 263.5               | -6.24             | -35.90          | -5.58            | -33.41           |

The measurement data for $\delta^{18}O$ and $\delta^2H$ isotopes in groundwater in the Raimanuk area are shown in table 5. The isotopic values of groundwater are plotted on RMWL to determine the relationship between groundwater and meteoric water (figure 4) and to estimate the height of the recharge area. This can be done by using the equation of the chart of $\delta^{18}O$ and $\delta^2H$ rainwater isotope depletion with altitude in figures 5 and 6 are as follows [7,8]:

$$\text{Elevation} = -230.71 \delta^{18}O - 916.39$$  \hspace{1cm} (8)

$$\text{Elevation} = -28.354 \delta^2H - 596.95$$  \hspace{1cm} (9)

**Table 5.** Raimanuk groundwater isotope measurement

| Type of sample | Coordinate (UTM) | Elevations (masl) | $\delta^{18}O$ (%) | $\delta^2H$ (%) |
|---------------|------------------|------------------|-------------------|----------------|
| SB-1         | 707733           | 8972046          | 410.6             | -5.02          | -34.4            |
| SB-2         | 706335           | 8973484          | 400.5             | -5.77          | -36.9            |
| SB-3         | 702988           | 8970826          | 371.7             | -4.05          | -23.8            |
| SB-4         | 702810           | 8968791          | 352.6             | -5.68          | -36.3            |
| SB-5         | 702085           | 8967725          | 338.1             | -5.68          | -35.6            |
| SB-6         | 700954           | 8971937          | 330.2             | -5.28          | -34.4            |
| SB-7         | 698231           | 8969363          | 368.3             | -5.38          | -33.9            |
| SB-8         | 697004           | 8969048          | 356.5             | -5.15          | -34.2            |
| SB-9         | 696302           | 8976271          | 362.5             | -5.34          | -34.7            |
| SB-10        | 704153           | 8973589          | 374.7             | -5.8           | -36.5            |
| SG-1         | 705572           | 8970184          | 369.1             | -3.68          | -24.9            |
| SG-2         | 705063           | 8974468          | 387.6             | -4.52          | -28.3            |
| SG-3         | 703256           | 8970077          | 347.7             | -4.38          | -28              |
| SG-4         | 701424           | 8972746          | 365.5             | -4.41          | -26.9            |
| SG-5         | 699665           | 8968572          | 343.2             | -4.08          | -26.8            |
| SG-6         | 696654           | 8965451          | 368.6             | -4.06          | -27.8            |
| MA-1         | 711502           | 8967845          | 676.2             | -4.84          | -28.5            |
| MA-2         | 708899           | 8966579          | 533.7             | -4.74          | -27.9            |
Based on figures 4-6, groundwater in the Raimanuk area can be classified into 4 groups. Group I consists of groundwater SB-2, SB-4, SB-5, SB-10, located at an elevation of 308-401 masl, which is
groundwater sourced from meteoric water because it almost intersects with RMWL. After inserting the groundwater isotope ratio into equations 8 and 9, the elevation of the recharge range is between 394-450 masl. Group II consists of groundwater SB-1, SB-6, SB-7, SB-8, SB-9, located at an elevation of 330-411 masl, which does not show groundwater originating from a higher elevation but still comes from meteoric water. After inserting the isotope ratio values of δ¹⁸O and δ²H of groundwater into equations 8 and 9, the recharge elevation is the same as the elevation range of the groundwater sample, which ranges from 330-411 masl. Therefore, groundwater in this group is considered to come from local rainwater infiltration.

Group III consists of groundwater MA-1, MA-2, MA-3, MA-4, located at an elevation of 392-677 masl, which is groundwater sourced from meteoric water. The recharge elevation is lower than the elevation of the sample after plugging the groundwater isotope ratio into equations 8 and 9. This is presumably because the groundwater samples in this group were taken at different seasons from other groundwater samples so that groundwater in this group can be said to come from local rainwater infiltration. Based on that reason, the groundwater recharge elevation for this group is the same as the sample elevation, which ranges from 392-677 masl.

Group IV consists of groundwater SB-3, SG-1, SG-2, SG-3, SG-4, SG-5, SG-6, located at an elevation of 343-388 masl. Groundwater in this group is still sourced from meteoric water but has been affected by evaporation characterized by the distribution pattern of the isotope ratio away from RMWL. This is supported by groundwater samples taken from 6 dug wells and 1 community drilled well from shallow aquifers. Groundwater in shallow aquifers is very susceptible to being affected by evaporation. A line of groundwater integration in this group is drawn up to determine the range of the recharge elevation referred to as the Evaporation Water Line (EWL). The EWL line is extended until it intersects the RMWL so that the point of intersection between the two lines is obtained. The intersection is assumed to be the isotopic composition value without being affected by enrichment due to evaporation [20]. The range of recharge elevation is obtained by plotting the value of the intersection point into equations 8 and 9. It is accepted that the recharge elevation is lower than the sample elevation. This is due to the influence of seasons such as group III. From figure 4, it can be seen that the point of intersection of the lines and the isotopic composition value are close to the MA-4 groundwater, so it is suspected that the groundwater in group IV is sourced from the recharge elevation in the same range as the MA-4 groundwater elevation, which is 412 masl.

Of the three groundwater groups, namely groups I, III, and IV, groundwater recharge is at an elevation above 390 masl. Areas located at elevations above 390 masl are mandeu hills. Therefore, the groundwater recharge area in the Raimanuk area is the Mandeu hills. Administratively, the groundwater recharge area covers parts of Raimanuk District, West Tasifeto District, and Nanaet Duabesi District. Based on the hydrogeology, the groundwater recharge area in the Raimanuk area is formed by limestone and siltstone lithology. The aquifers in the area generally have limited groundwater flow and water infiltration in fractures, fissures, and channels [20]. The other groundwater group, namely group II, is sourced from local rainwater infiltration. This is supported because this area is formed by lithology in the form of alluvial plains which can be used as a reservoir for free aquifer groundwater [21].

6. Conclusion

The results of stable isotope and hydrochemical analysis of groundwater can determine the area of groundwater recharge. Groundwater in the Raimanuk area can be divided into 4 groups based on the elevation of origin. Groundwater in group I comes from recharge elevations between 394-450 masl, group II comes from recharge elevations between 330-411 masl, group III comes from recharge elevations between 392-677 masl, and group IV comes from recharge elevations at 412 masl. All groundwater samples are still sourced from meteoric water. Areas located at elevations above 390 masl
are recharge areas for groundwater in the Raimanuk area. The groundwater recharge area in the study area is located in the Mandeu hills covering parts of Raimanuk District, West Tasifeto District, and Nanaet Duabesi District. The hydrochemical facies of groundwater is CaHCO$_3$, NaKHCO$_3$, and there is no dominant type HCO$_3$. The dominant groundwater with the composition of Ca, NaK, and HCO$_3$ is influenced by weathering rocks with carbonate and siliciclastic materials. All groundwater samples in the Raimanuk area were sourced from shallow or young groundwater characterized by enrichment of HCO$_3$. Further research needs to be done to state the shape of the aquifer and the pattern of groundwater flow in more detail.

The quality of groundwater from all samples taken is considered good and is included as freshwater. For the time being, the use of groundwater for household needs and irrigation of agricultural land is still considered suitable, but standard water quality tests must also support this. In addition, groundwater in the Raimanuk area comes from free aquifers, and the Raimanuk area is classified as a drought-prone area. The reason is, if the dry season is long, groundwater in the Raimanuk area will run out. With the results of this study, it is expected that the role of the government and the community in managing groundwater properly and maintaining the surrounding environment so that groundwater recharge areas are correctly maintained.

References
[ 1 ] Belu Regency Central Statistics Agency 2020 Belu Regency in Figures for 2020 Belu
[ 2 ] North Timor Tengah Regency Central Statistics Agency 2020 North Timor Tengah Regency in Figures for 2020 North Timor Tengah
[ 3 ] Malaka Regency Central Statistics Agency 2020 Malaka Regency in Figures for 2020 Malaka.
[ 4 ] National Disaster Management Agency 2019 Catalog of Drought-Prone Villages/Urbans Jakarta
[ 5 ] ESDM Ministry Press Release 2019 Groundwater Utilization Must Pay Attention to Environmental Balance No. 683.Pers/04/SJI/2019 November 28, 2019
[ 6 ] The Republic of Indonesia 2018 Regulation of the Minister of Energy and Mineral Resources Number 31 of 2018 concerning Guidelines for Determining Groundwater Conservation Zones LL KESDM BN RI 2018 No. 733 Jakarta
[ 7 ] Mazor E 2004 Chemical and Isotopic Groundwater Hydrology Third Edition Marcel Dekker Inc. New York 453
[ 8 ] Clark I 2015 Groundwater Geochemistry and Isotopes First Edition CRC Press Boca Raton 456
[ 9 ] Maria R et al 2021 Groundwater Recharge Area Based on Hydrochemical and Environmental Isotopes Analysis in the South Bandung Volcanic Area Indones. J. Chem. 2021 21 (3) 609 – 625
[ 10 ] Sudaryanto and Lubis R F 2011 Determining The Location of Groundwater Recharge Using Stable Isotope Tracker $^{18}$O and $^2$H in The Lowland Groundwater Basin Semarang, Central Java Geological and Mining Research Vol. 21 No. 2 121 – 129
[ 11 ] Suwitodirjo K and Tjkosapoteo S 1996 Geological Map Sheet Kupang-Atambua Timor, Geological Research and Development Center Bandung Scale 1:250.000 2 sheets
[ 12 ] Todd D K and Mays L W 2005 Groundwater Hydrology 3rd Edition John Wiley & Sons Inc. Hoboken 652
[ 13 ] Fetter C W Jr 2014 Applied Hydrogeology: Pearson New International Edition Fourth Edition Pearson Essex 616
[ 14 ] Cahyadi A and Hidayat W 2017 Analysis of Hydrogeochemical Characteristics of Groundwater in Panggang Coral Island, Seribu Islands, DKI Jakarta Geography Journal Vol. 9 No.2 99-108
[ 15 ] Schmoll O, Howard G, Chilton J, and Chorus I ed 2006 Protecting Groundwater for Health: Managing the Quality of Drinking-water Sources IWA Publishing London 83 – 85
[ 16 ] Nuryana S D, Setiawan R, Assegaf A, and Dian A 2019 Chemical Analysis of Formation Water
in Tertiary Limestone in Ciseeng Bogor Region Petro Journal 2019 Vol. VIII No. 4 178 – 185

[17] Mook W G 2000 Environmental Isotop in Hydrological Cycle: Volume I UNESCO-IAEA Groningen 1 – 145

[18] Hem J D 1985 Study and Interpretation of The Chemical Characteristics of Natural Water Water Supply Paper 2254 U.S Geological Survey 272

[19] Gemilang W A, Ridwan N N H, and Wisha U J 2019 Characteristic of Unconfined Aquifer Hydrogeochemistry in Weh Island Coastal Area, Aceh Journal of Water Resources Vol. 15 No. 1 27 – 38

[20] Seizarwati W 2019 Determination of the Watershed in Yamdena Island with the Stable Isotope Method Proceedings of the 12th National Earth Seminar Geological Engineering Gadjah Mada University E003PRO 703 – 722

[21] Soedjatmiko B 2010 Survey of Clean Water Availability Using Geoelectric Method in Barren Areas, Timor, NTT Proceedings of the National Seminar on Limnology V Physics Research Center – LIPI 312 – 319

[22] Wang et al 2014 Using Hydrochemical and Isotopic Data to Determine Sources of Recharge and Groundwater Evolution in an Arid Region: a Case Study in the Upper-Middle Reaches of the Shule River Basin, Northwestern China Environ Earth Sci Springer 15

[23] Suwarto A B, Hadian S D, Hendarmawan 2015 Hydrogeology of Batujajar CAT with Geological Study Approach and Isotopes 18O and 2H 2nd National Seminar of the Faculty of Geological Engineering, Padjadjaran University 67 – 77

[24] Zhou P, Li M, Lu Y 2017 Hydrochemistry and Isotope Hydrology for Groundwater Sustainability of the Coastal Multilayered Aquifer System (Zhanjiang, China) Geofluids Hindawi Vol. 2017 ID 7080346 19

[25] Afriyani M P, Santosa L W, Adji T N 2020 Analysis of Groundwater Hydrogeochemical Genesis Using Rectangular Piper Diagram in Coastal Area Geographical Communication Media Vol. 21 No. 1 11 – 11

[26] Boulok M, Putra D P E, Wilopo W 2014 Chemical Composition and Hydraulic Connectivity of Springs in The Southern Slope of Merapi Volcano J. SE Asian Appl. Geol. Vol. 6 (1) 1 – 11

[27] Manta W F, Hendrayana H, Amijaya D H 2021 Determination Of Groundwater Recharge Area In Raimanuk And Surroundings, Timor Island IOP Conf. Ser.: Earth Environ. Sci. Vol. 930 012059 11

[28] Base Map Source: Geospatial Information Agency 2017 Indonesian Earth Map Scale 1:25.000