Preliminary Conceptual Model of Hydrogeological System in The Raimanuk and its Surrounding Area on the Timor Island

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Abstract. There are several areas with groundwater potential in Timor island, one of which is the Raimanuk and its surrounding area. This study aims to determine the hydrogeological system in the Raimanuk and its surrounding area. The hydrogeological system is determined by the geological conditions, geomorphology, lithology, and groundwater flow patterns. Geological conditions and groundwater flow patterns are provided by conducting a field investigation. Twenty shallow wells and four springs were measured to provide the groundwater contour. The geoelectrical survey was conducted at eleven points to analyze subsurface lithology. The results show that the geology of the study area is dominated by alluvium (west area), carbonate siltstone, and crystalline limestone (middle to the east area). There are two types of aquifers in the study area: unconfined aquifers and confined aquifers with gravel sandstone lithology. The groundwater flow pattern shows that the groundwater movement is from the east to the southwest. Moreover, the groundwater also moved from the northern, southern, and western of the study area. It is implied that the aquifer's shape at the Raimanuk area is formed as a bowl-like shape influenced by the geological, geomorphological conditions.

Keywords: hydrogeological system, geoelectrical survey, groundwater flow, Raimanuk Area

1. Introduction
The province of East Nusa Tenggara is known to have a more dry climate than other parts of Indonesia. Its dry climate is due to its geographical position, relatively close to Australia, primarily a desert climate. Although the province is archipelagic, humidity is relatively low, especially between April to October when the wind blows from mainland Australia, the annual rainfall, and monsoons [1]. Nevertheless, several areas have groundwater potential in Timor island, one of which is the Raimanuk and its surrounding area. Raimanuk sub-district is even included in the area categorized as agropolitan due to its significant agricultural potential [2].

Determining the hydrogeological system in the Raimanuk and its surroundings is important to managing the water resources utilization in the area. Thus, a study about geology, geomorphology, subsurface conditions, and groundwater flow is needed to conduct as the first step in further studies. There is a groundwater basin in the study area named Aroki. According to the regional hydrogeological map,
the recharge area of Aroki groundwater basin is located on the north outside of the study area, while the discharge area is on the west inside the study area [3]. This research reviews the hydrogeological system from the mountains on the east to the lowlands, which are the discharge areas of the Aroki groundwater basin on the west of the study area.

The study area is administratively located in Raimanuk. Its surroundings cover 146.352 km² consisting of 7 sub-districts in 3 different regencies; the first regency is Belu with Raimanuk Tasifeto Barat, and Nanaet Duabesi as the sub-districts. The second regency is Timur Tengah Utara with Biboki Utara and Biboki Tan Pah as the sub-districts. The third regency is Malaka, with Laenmanen and Malaka Timur as the sub-districts, as seen in Figure 1.

The topographic conditions in the study area, especially those in the administrative area of Belu Regency, are flat areas combined with hills and mountains, with varying heights at an altitude of 0 to +1500 masl, with highlands located in the eastern region [2]. The rocks formations in the study area are divided into allochthon and autochthon formations [4]. The autochthon formation consists of Bisane formation (Pb), Noele formation (Qtn), Coral limestone (Ql), and Alluvium (Qa). Meanwhile, the allochthon formation consists of Mutis complex (pPm), Maubisse formation (TrPmv/TrPml), and Bobonaro complex (Tmb) [5].

![Figure 1](image_url)

Figure 1. The study area of the hydrogeological system research in the Raimanuk and its surroundings

2. Methodology
It is necessary to study several conditions to overview the hydrogeological system in the Raimanuk area and its surroundings. Each study has a different method, such as the field investigation, to determine the geological and geomorphological condition. The geoelectrical survey was conducted to identify the sub-surface condition and groundwater level measurement to obtain groundwater flow patterns.
2.1. Field Investigation
Field investigation includes the collection and review of existing conditions on the site, including geological, geomorphology, topography, and other conditions that might affect the suitability of the site for its intended use and potential impacts on natural resources [6]. The results of field investigations will later be depicted on geological and geomorphological maps. Geological mapping in this research is carried out by observing rock outcrops. An engineering geological map should ideally be able to display some aspects as follows: 1) Soil and rock conditions include their physical and mechanical properties and their distribution 2) Geological structure data includes types of geological structures and their distribution 3) Geomorphological conditions include the slope at the mapping location existing landslide point 4) Hydrogeological conditions include groundwater level [7][8].

In addition to the geological map, a geomorphological map obtained from field investigation was also produced, combined with digital elevation model (DEM) data. Geomorphology consists of 4 main aspects: morphological aspect, morphogenesis aspect, morphochronological aspect, and morpho-associative aspect. The aspect used in this research is the morphological aspect, which consists of morphography and morphometry. Morphography is a defining aspect of the geomorphology of an area, such as plains, hills, mountains. In comparison, morphometry is a quantitative aspect to describe the geomorphological slope of an area, such as slope, height, direction, and roughness of the land [9][10].

2.2. Sub-Surface identification
The geoelectrical resistivity method has been widely used in environmental and geotechnical investigations. This method aims to determine the subsurface resistivity distribution by making measurements on the ground surface. From these measurements, the true Resistivity of the subsurface can be estimated. The ground resistivity is related to geological parameters such as the mineral and fluid content, porosity, and degree of water saturation in the rock [11]. The geoelectrical survey as Vertical Electrical Sounding (VES) was conducted at 11 locations in the study area and then processed into 2D and 3D data.

2.3. Groundwater Flow Direction and Pattern determination
The water table is needed to determine the direction of water flow. The direction of water flow can be obtained by measuring the water table from neighboring wells in meters above sea level (masl). The depth of the water table in a well is measured relative to an agreed-upon mark at the top, for example, the edge of the casing. Measuring the water table can be done by using measurement tapes. Figure 2 shows how to obtain the depth of the water table in masl. The first step is measuring water level depth from the edge of the well casing (AC). Then, measure the height of the well casing (AB). Depth of water table (BC) can be calculated from the subtraction of AC and AB. The elevation of the water table can be obtained by measuring the ground elevation. Subtraction between the elevation of ground level and depth of water table will produce a water table in masl [12].

![Figure 2. The water table measurement illustration [12].](image-url)
The water table maps consist of equipotential lines as contours of equal water table altitudes. The direction of groundwater flow will be obtained through the equipotential lines, as seen in Figure 3. The water table map from 20 shallow wells and four springs is plotted according to the coordinates to create a raster of the equipotential lines and flow direction using the GIS.

![Figure 3](image)

**Figure 3.** The equipotential lines and flow direction interpretation [12].

3. Result and Discussions

3.1. Geological condition

Sedimentary rocks dominate the geology of the study area with a structure in the form of layers, laminates, and massive. The distribution of rocks tends to be irregular, caused by the Bobonaro complex that dominates the study area [5]. The existence of geological structures is also challenging to find due to weathering. The results of field investigations and the study area's geology are divided into seven units; the distribution of rocks and illustrations of geological profiles can be seen in Figure 4. The definition of the unit is based on regional geological data, which is combined with data obtained directly from the study area. The naming of the lithological units is based on the dominance of rocks in the area, with boundaries determined through relief observations and field data. The units, when sorted from oldest to youngest, are as follows.

a. **Carbonate siltstone 1 unit**

The carbonate siltstone 1 unit is part of the pre-Perem Bisane Formation, the oldest unit in the study area [5]. Spread in the northeast of the study area, including the morphology of hills with gentle slopes. The general condition of this rock unit outcrop is relatively fresh if it is not covered with soil or vegetation. The results of the field description show that the rock has a brownish white color, with a layered structure, silt grain size, good sorting, closed packaging, siliciclastic, and carbonate material composition. The lithology found in this unit is dominated by carbonate siltstone. In addition, crystalline limestone, carbonated claystone, and coral limestone were also seen as inserts.

b. **Crystalline limestone unit**

The crystalline limestone in this study area is part of the Perem to Triassic Maubisse Formation [5]. It appears in the southeast of the study area with hilly morphology with steep slopes. The general condition of these rock outcrops tends to be fresh, with little soil formed on it. The results of the field description show that the rock has a fresh white color, weathered blackish white color, massive structure, sand grain size, good sorting, closed packaging, the composition of bioclastic material, and carbonate material. The lithology is dominated by crystalline limestone and wackestone.

c. **Carbonate siltstone 2 unit**

The carbonate siltstone 2 unit belongs to the Bobonaro Complex [5], a mixed rock with rock fragments up to the size of a hill on a scaly clay matrix [4]. It appears in most of the study areas with a slightly sloping hillside morphology, sloping to slightly steep, this unit. The general condition of these rock outcrops tends to be weathered with many soil-formed and intermingling layers. The rock color is white-brown, red, black, greenish-white, with a layered or laminated structure, silt grain size, good sorting,
closed packaging, siliciclastic material composition, carbonate material, and iron oxide minerals. In addition to carbonate siltstone, such as calcarenite, rudstone, gravely limestone, grainstone, and tuffaceous marl as inserts.

Figure 4. Geological units & outcrops

d. Porphyry basalt unit
The porphyry basalt unit in the study area is part of the Maubisse Formation but is interpreted as a fragment of the Bobonaro Complex. Spread in the southeast of the study area, including the morphology
of hills with rather steep and sloping slopes. The general condition of the outcrop of this rock unit tends to be weathered, with only a few visible fresh minerals. The results of the field description show that the rock has fresh gray-brown color and weathered brown color, with a massive structure, porphyroafanitic texture, 0.5-2 mm phenocryst size, <0.5 mm base mass, composition in the form of plagioclase and mafic minerals. In some places, the rocks have been altered to appear green minerals, which are considered zeolite minerals.

e. Coral limestone unit
This unit is part of the Tertiary-Quarter Noele Formation [5]. Spread in the north of the study area, which includes hills with rather steep slopes. The general condition of the outcrop of this rock unit is quite weathered, with thick soil on its surface. The results of the field description show that the rock has a white-brown color, with a layered structure, the grain size of sand to gravel, poor sorting, open packaging, the composition of bioclastic material, and carbonate material. Coral limestones dominate the lithology found in this unit. In addition, wackestone limestone was also found.

f. Wackestone unit
The wackestone unit is part of the Quaternary Coral Limestone [5]. Spread in the southern part of the study area, including the morphology of hills with gentle slopes. The general condition of these rock outcrops tends to be fresh, with little soil formed on its surface. The results of field descriptions show that the rock has a fresh white-brown color, weathered blackish-brown color, massive structure, fine sand to silt size, good sorting, closed packaging, carbonate material composition. Wackestone and coral limestone are dominated in this unit.

g. Alluvium unit
This unit is spread in the western part of the study area, including plain morphology covering more than 50%. It is located in the Aroki groundwater basin discharge area. The constituent lithology of this deposit originates from the surrounding hills, which transport sand, gravel, and boulder-sized materials through rivers. These deposits were formed during the Holocene. On-field observations, the deposits found were brown and white-brown with rounded to subrounded shapes. The size is dominated by sand and gravel. In addition, there is sedimentary material that ranges from gravel to lumps but in much less quantity. Since dominated by sand and gravel, which have relatively high porosity and permeability [12], the alluvium unit potentially infiltrates and stores the groundwater from other units in the higher areas around it.

3.2. Geomorphological condition
Based on the morphographic and morphometric aspects referring to the van Zuidam classification [9], the geomorphology of the study area is divided into five geomorphological units as shown in Table 1, with a steep slope on the east side of the study area and gradually sloping towards the west side of the study area (Figure 5). Steeper slopes are also found on the north, south, and west outside of the study area, portraying that the western part of the study area is flatter with lower elevations than the surrounding area. This shape significantly affects the groundwater table furthermore the groundwater flow direction and pattern, especially for the unconfined aquifer.

| No. | Relief (Topography) Unit | α (%) | Δh (m) | Coverage (m²) |
|-----|--------------------------|-------|--------|---------------|
| 1   | Flat or almost flat      | 0 – 2 | < 5 | 70 |
| 2   | Undulating               | 3 – 7 | 5 – 50 | 13.5 |
| 3   | Undulating - rolling     | 8 – 13 | 25 – 75 | 34 |
| 4   | Rolling - hilly          | 14 – 20 | 50 – 200 | 22.6 |
| 5   | Hilly - steply dissected | 21 – 55 | 200 – 500 | 6 |
3.3. Sub-surface identification

Geoelectrical Resistivity was conducted in 11 locations to represent sub-surface conditions with VES Method. The VES results show rock layers with resistivity value between 20 - 100 ohm meters and are interpreted as gravel sandstone at a depth of 2-10 m and 20-100 m (Figure 6). Those rock layers have the potential value as an aquifer due to the nature of gravel sandstone with large porosity and permeability. Gravel sandstone located at a 20-100 is classified as confined aquifers because it is overlain by clay. In contrast, shallower gravel sandstone layers are classified as unconfined aquifers because they are covered directly by topsoil. The VES interpretation data is then processed into 2D and 3D interpretations to see the larger picture of the subsurface condition in the study area, as seen in Figure 7. Massive rocks with Resistivity values above 200 ohm-meter dominate the surface layer to a depth of 100 m in the east area. In the middle area, the lithology a depth of 100 m gradually turns into gravel sandstone and silt with Resistivity value varies from 60-140 ohm-meter. Towards the west, the lithology on the surface to a depth of 100 m changes to be silt and clay with gravel sandstone with the Resistivity value under 20 ohm-meter.
Figure 6. Vertical Electrical Sounding (VES) interpretation
3.4. Groundwater pattern and flow direction

Results of water table measurement are shown in Table 2. The water table varies between 334.18 – 676.18 masl. The lowest water table is at SG 12, SG 13, and SG 14 on the southwest of the study area or administratively located at Tualene Village and Tasain Village. The highest water table is at MA 1, which is located at Mandeu Mountains. The pattern and direction of groundwater flow are shown in Figure 8. The direction of groundwater flow dominantly flows from the east side heading to the southwest. Moreover, the groundwater also moved from the northern, western, and southern of the study area. The groundwater flow pattern in Raimanuk and its surroundings has a bowl-like aquifer shape, is dominantly influenced by geological and geomorphological conditions.

| No | Sample Name | Ground Surface (masl) | Depth of Water Table (m) | Water Table (masl) |
|----|-------------|-----------------------|--------------------------|-------------------|
| 1  | SG 1        | 367.96                | 9.59                     | 358.37            |
| 2  | SG 2        | 369.10                | 8.90                     | 360.20            |
| 3  | SG 3        | 387.58                | 1.61                     | 385.97            |
| 4  | SG 4        | 385.82                | 5.08                     | 380.74            |
| 5  | SG 5        | 349.40                | 0.76                     | 348.64            |
| 6  | SG 6        | 349.19                | 0.72                     | 348.47            |
| 7  | SG 7        | 347.69                | 0.10                     | 347.59            |
| 8  | SG 8        | 351.74                | 0.60                     | 351.14            |
| 9  | SG 9        | 359.51                | 1.70                     | 357.81            |
Table 2. Ground surface elevation and water table (Continued)

| No | Sample Name | Ground Surface (masl) | Depth of Water Table (m) | Water Table (masl) |
|----|-------------|-----------------------|--------------------------|--------------------|
| 10 | SG 10       | 365.47                | 5.74                     | 359.73             |
| 11 | SG 11       | 368.29                | 6.22                     | 362.07             |
| 12 | SG 12       | 337.00                | 2.82                     | 334.18             |
| 13 | SG 13       | 338.26                | 1.95                     | 336.31             |
| 14 | SG 14       | 338.83                | 3.27                     | 335.56             |
| 15 | SG 15       | 343.17                | 0.46                     | 342.71             |
| 16 | SG 16       | 350.28                | 1.16                     | 349.12             |
| 17 | SG 17       | 361.56                | 5.83                     | 355.73             |
| 18 | SG 18       | 370.85                | 3.58                     | 367.27             |
| 19 | SG 19       | 368.64                | 3.13                     | 365.51             |
| 20 | SG 20       | 370.00                | 2.47                     | 367.53             |
| 21 | MA 1        | 676.18                | 0                        | 676.18             |
| 22 | MA 2        | 533.71                | 0                        | 533.71             |
| 23 | MA 3        | 392.03                | 0                        | 392.03             |
| 24 | MA 5        | 412.64                | 0                        | 412.64             |

Figure 8. Groundwater pattern and flow direction
4. Conclusion
The conclusions of this research are:

a. Sedimentary rocks dominate the geology of the study area with a structure in the form of layers, laminates, and massive, which are divided into seven units. The west area is dominated by alluvium, while the middle to the west areas is dominated by carbonate siltstone and crystalline limestone, and porphyry basalt in the higher areas.

b. There are two types of aquifers in the study area: unconfined aquifers at the depths of 5-10 m and confined aquifers at the depths of 20-100 m. Both were located in gravel sandstone lithology. 2D interpretation shows that lithology of the west area is dominated by silt and clay sediment. The middle area was gravel sandstone and more massive rocks in the east area; this is similar to the geological surface investigation result.

c. The groundwater flow pattern in an unconfined aquifer shows that most groundwater movement is from the east with slopes of 21% -54% to the southwest with less than 2% in the Tualene Village and Tasain Village. Moreover, the groundwater also moved from the northern, southern, and western of the study area. These results implied that the aquifer's shape at Raimanuk and its surrounding area is formed as a bowl-like shape and dominantly influenced by the geological and geomorphological conditions.

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