

The geomorphology and hydrogeology of the karstic Islands Maratua, East Kalimantan, Indonesia: the potential and constraints for tourist destination development

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Abstract. Maratua Island is one of the islands of Berau District, East Kalimantan which has great potential of natural beauty for tourism development. The area currently is one of famous tourist destination in East Kalimantan which is a carbonate reef built-up or so-called karst island. This paper is an endeavor 1) to unveil geomorphological and hydrogeological characteristics of the island, and 2) to recommend Island development as a tourist destination. Maratua Island is a V shape atoll with the open lagoon. Six geomorphological units were found on the island, i.e., fringing reef, beach, marine terrace, karst ridge, structural valley, and lagoon. Caves are also found in the karst ridge and the coast as an inundated passage. Three structural depressions in the karst ridge are other unique geomorphological feature in the area of which a marine lake environment with jellyfish is inhabited. The island is typified by two different aquifer units, i.e., porous media and fractured media aquifer. Porous aquifer lies on the beach of Boibukut area. Fractured-aquifer characterizes the other geomorphological units in the area. Freshwater accordingly is found in the beach area with a limited amount. Unfortunately, the groundwater in the marine terrace and karst ridge are saline. Maratua Island has enormous potential for tourism destination development. The major tourist activities in the area based on the geomorphological unit are snorkeling and diving (in fringing reef and lagoon), hiking, cave exploration and marine lake exploration and cave diving (in karst ridge and structural valley); recreation and picnic (beach). The major limitation in the area is a shortage of freshwater resource and land. Limited water supply should be extracted from the beach area of Bohe Bukut village. Groundwater extraction from the beach area of Bohe Bukut must be for drinking water only. Supply of drinking water should be substituted from collected rainwater or desalination from sea water and water in the cave. Restrictions in the number of visitors and lodging development should also be considered.

1. Introduction

Indonesia is the biggest archipelagos countries in the world. The number of islands in Indonesia is 16.056 islands (Berita Geospasial BIG, 2017). As such, Indonesia islands have various physical characteristics, including geomorphology and hydrogeology. Geomorphology is the study of landforms and processes taking place on the earth surface, and the relationship between these landforms and processes in terms of spatial context [1]. The primary object of geomorphological studies is landforms. The geomorphological characteristics of a surface will affect the hydrogeological conditions of an area [2].

Karstic island is one of the islands found in some Indonesian Island. Karst landform is considered unique, where it has typical morphological and hydrological conditions due to the development of secondary porosity [3]. Regulation of the Minister of Energy and Mineral Resources (ESDM) No 17



of 2012 specifies that karst is a landscape that is formed as a result of the dissolution of limestone or dolomite.

Maratua Island is one of the small islands of the Derawan-Maratua complex islands, situated in Berau Regency, of the East Kalimantan Province. The island is one of the carbonate islands and karst islands in Indonesia [4]. Maratua Island has great potential of natural beauty for tourism development. Presently, tourism in Maratua Island has also been growing and attracted a more significant number of both domestic and foreign tourists. This development in tourism is also responded by investment and infrastructure development as well. A carpet of a white-sand beach and, karst caves, reef, and a saltwater lake constitute the attraction of tourism in Maratua Island.

Becoming one of the leading national and regional tourist destinations makes the development in Maratua Island is growing very fast. Tourism facilities, i.e., roads, inns, airport, and other public facilities have been built in the Island. The fast development in a small island of Maratua obviously will affect its environmental conditions. The development, therefore, must consider its carrying capacity on the island. The carrying capacity of the environment is defined as the number of people or conditions that can be supported by resources in the area or ecosystem [5].

Identifying the potential and the existing limiting condition of an area is an important step as a framework for appropriate and sustainable development. The Maratua Island which has high potential for tourist destination also has its limitation in term of geomorphological and geohydrological aspects. This paper accordingly aims at determining the geomorphological and geohydrological characteristics of Maratua Island, and giving recommendations for the development based on the existing potential and constrains.

2. Study Area

Maratua Island is the easternmost island of East Kalimantan, bordering the Indonesia Archipelago with the Malaysia and Philippines. It lays at the 2°15'12" North Latitude and 118°38'41" East Longitude. Maratua is considered as a small island of which the land area is less than 1,000 km² and has a permanent population of fewer than 100,000 inhabitants [6]. The population number of the Maratua Island is 3,402, and the area is 4,119.54 km². Administratively, the island belongs to Berau Regency. The Maratua Island Subdistrict has four villages, namely BoheSilian, Payung-Payung, BoheBukut, and TelukAlulu. Maratua Island consists of a main island called Maratua and a group of small isles situated within its lagoon, i.e. Semut Island, Siddau Island, Kokok Island, Pabahanan Island, Bulingisan Island, and Andongabu Island.

Physiographically, Maratua Island is situated in the northeast part of Kalimantan which is in the tip of Mangkalihat high. The island is 60 km away from the mainland of Kalimantan separated by shallow sea [7]. The eastern part of Maratua Island is bordered by the slopes of the Makasar Strait. Geologically, Maratua Island is composed of limestone and located at the fringe of the NW-SE bearing Maratua Fault (figure 1.). The Maratua Island morphology, therefore, is governed by this fault to which its shoreline extends parallel to the fault orientation.

3. Methods

The main methods used in this research were remote sensing interpretation and field survey. A field survey was conducted in 2012 up to 2015. Mapping of landforms in Maratua Island was undertaken using remote sensing image interpretation which was verified by field checking. The remote sensing images used for the interpretation were Landsat TM 7 and ALOS. A field survey was conducted through geomorphological and hydrogeological surveys; including landform observation and measurement, cave mapping, groundwater level measurement, plotting of potential tourist attraction. Most of these potential tourist destination attraction was obtained from local people information. Qualitative measurement of water quality conditions were carried out in several caves and resident's wells by tasting the water.

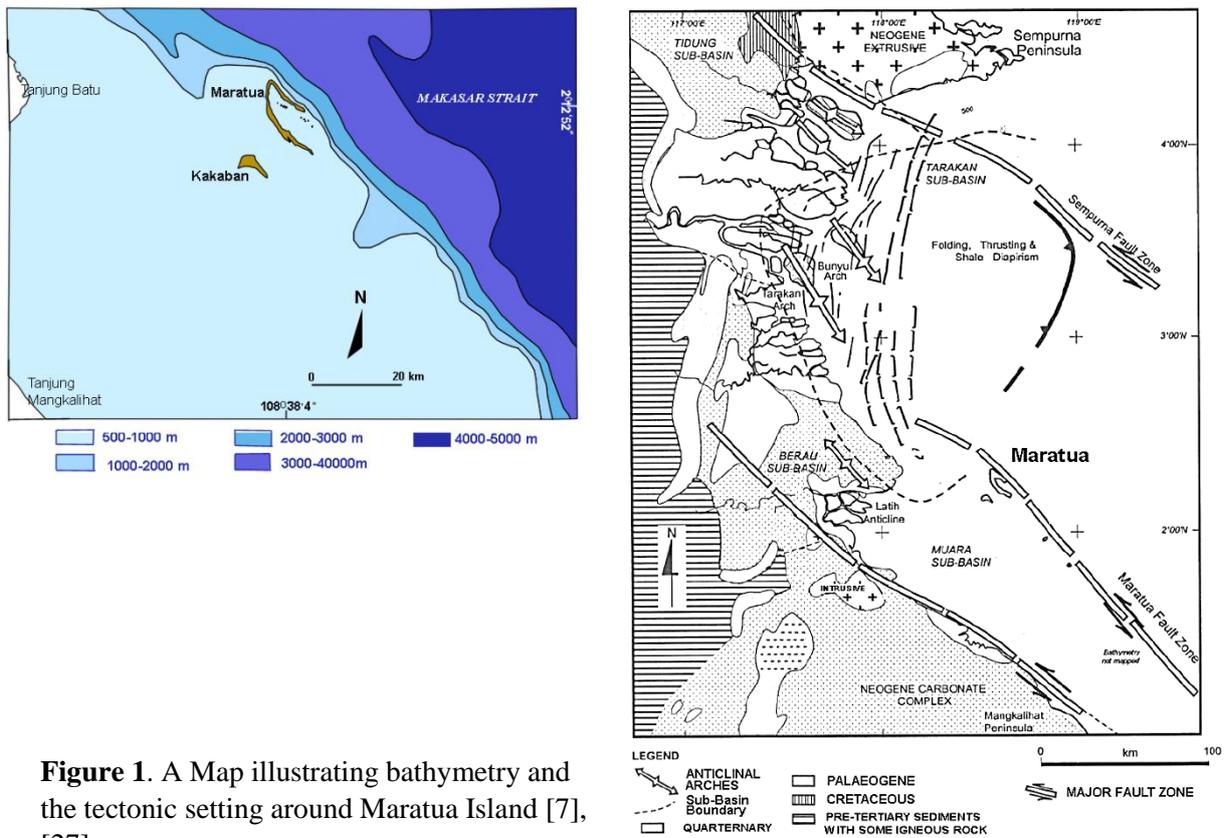


Figure 1. A Map illustrating bathymetry and the tectonic setting around Maratua Island [7], [27].

4. Result and Discussions

4.1. Geomorphology

The tectonic setting which primarily controls the formation of Maratua Island has resulted in a large number of structural features to be found in the island. The island formation is governed by NW-SE fault, the rifting of Eocene-Quarter Makasar Strait, and uplifting [8] [11]. Exogenic processes in the area further modify the structural form into different landforms. The landforms of Maratua Island, hence, consists of structural, solution, marine, and organic form (see figure 2).

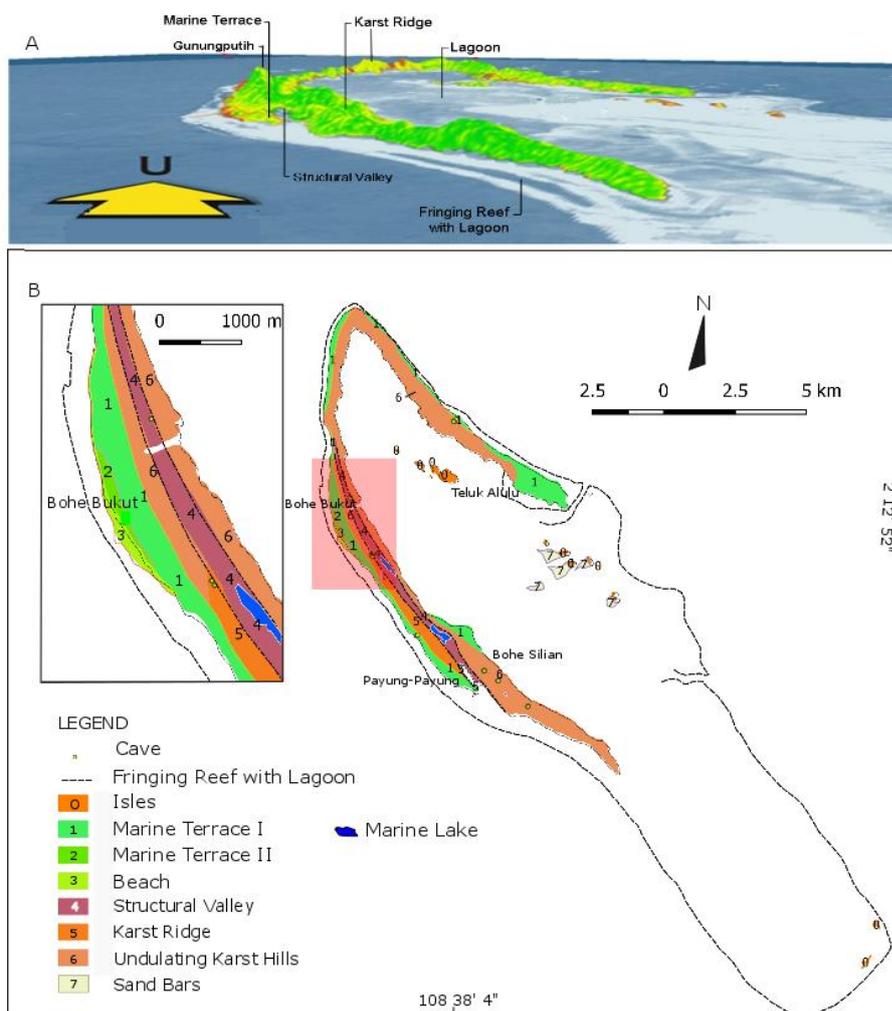


Figure 2. (a) morphological features of the Maratua Island in 3D view and (b) landforms of the Maratua Island.

Structural landform found in the Maratua Island is a structural valley which is associated with the NW-SE structural trend. The structural valleys in Maratua Island are filled with salt water forming a marine lake, namely Hajibuang, Tanabamban, Haji Mangku, and Siku Peninsula lake. The formation of marine lakes is suggested occurring during the last interglacial periods [12] [13]. The marine lake is comparable to the marine lake of the Misol Island complex described [28]. The planar shape of the marine lakes tends to extend with a ratio of their maximum width to their maximum doline length of about 1:3.

Table 1. Peaks of karst ridge in Maratua Island.

Nr.	Hills	Height (m from MSL)	Slope (degree)	Slope Form
1	Bohe Silian	80	25 -35	Concave
2	Gunung Putih	111 m	35-45	Concave
3	Bohe Bukit-Teluk Alulu	65 m	20-35	Concave

Since the Maratua Island is a karstic island, solution form is the most extensive landform in the Island. Karst ridge is one of the major positive karst forms. It has several peaks from the southwest to the northeast. The highest peak in Maratua Island is Gunung Putih protruding up to 111 m from MSL.

Single doline in Maratua Island develops in the middle slope of the karst ridge along with structural opening with the azimuth of 290 up to 310, coinciding with the dominant structural pattern.

In addition to the exokarst landform, caves are also found in the Island as an endokarst landform (table 2). The caves found in Maratua Island have unique and distinctive morphology. Most of the caves are structural controlled (fault or joint) caves whose narrow passage with a high cave ceiling. Few caves have a large chamber, i.e., Tangkapa Cave and Angkal-Angkal Cave.

Table 2. The Caves in Maratua Island.

Nr.	Cave Name	X	Y
1	Sembat	680678	241568
2	Tangkapa	679625	242479
3	Angkal-Angkal	679136	242826
4	Silandayan	676935	244428
5	Sipbig	677085	244183
6	Sukur	674758	247565
7	Mayat-Mayat	674554	248089
8	Pogah	675221	246891
9	Hapit Pogah	675187	246947
10	Organ	674445	248955
11	Jellau	676660	253437
12	Pahang	677594	251903
13	Penggunting	676793	244087

Conical forms such as those are found in most karst areas in Java [14]–[17], Sulawesi [18], [19], Papua [20] do not exist in Maratua Island. The geological structure governs the elongated shape found in the island. Joints and faults are controlling factors that cause elongated hills found on the Maratua Island. Karst hills, in general, belong to the asymmetric form. Another major karst form found in Maratua Island is doline. Doline is one of the karst landform hallmarks resulted from concentrated dissolution. Dolines in Maratua Island, according to Cvijic category [21]–[22] has a funnel-shape with the ratio of width to depth is about 1:2.

Marine landforms found in Maratua Island are marine terraces, beaches, and lagoons. Two marine terraces are found on the island. The first marine terrace elevates from 8 to 10 m MSL with a relatively flat to rolling topography. The marine terrace composed of uplifted Quaternary Reef. The width of the reef terrace varies from 200 m to 2 km. In the west, the marine terrace is wider than that in the eastern part of the island. The second terrace and beach composed of white sand of coral fragments and sand. Most of the beach in Maratua Island is very narrow (less than 50 m width). In the nearshore zone, Maratua island is characterized by an organic form of fringing reef morphology. Fringing reef development is more extensive in the western part and inner lagoon than that in the eastern part.

4.2. Hydrogeology

The aquifers in Maratua Island are composed of three rocks, i.e., Miocene limestone, quaternary coral limestone, and unconsolidated sand (figure 3). The three rocks then form different aquifers. Miocene limestone occupies the central part of the mainland of Maratua, forming karst ridge and undulated karst hills extending from Bohe Silian Village to Teluk Alulu Village, forming a V shape island. The ridge whose bedrocks are Miocene limestone is often found in a caving system.

The karst aquifers in Maratua Island are characterized by high fracture porosity resulting from joints and faults. Therefore, freshwater lenses as occurs in an Atoll [23]–[26] does not develop in

Maratua Island. An extremely high permeability typifies karst aquifers in the area. The water level ranges from 2 to 5 meters above sea level. The water level in the western arm of Maratua Island is higher compared to the eastern arm such as in Teluk Alulu. The water level in karst aquifers is highly fluctuated and is controlled by tide oscillation. The fluctuations of groundwater level in karst aquifers can reach 1.5 meters. The fluctuating groundwater in karst aquifers occurs because the wet caves in Maratua Island are connected to the sea through fissures/cracks and joints. Table 3 shows caves with underground water found in Maratua Island. Water found in most of the caves and are brackish to saline.

Quaternary coral limestone occupies the marine terrace located in food slop of karst ridge either on the outer side overlooking the open sea or on the inner side that overlooks the inner lagoon. Marine terraces are characterized by rocks dissolution cavities and coral structure cavities. The rocks in the marine terrace less hard compared to the Miocene limestone of the karst ridge and undulated karst hills. The groundwater level in this aquifer ranges from 2 to 3 meters. The depth of groundwater from the ground surface ranges from 5 to 8 meters. The groundwater level in terrace aquifer is also affected by tides. Aquifers of reef terraces have high productivity with water quality similar to that of Miocene limestone aquifer.

The third aquifer is composed of loose sand occupies the lower marine terrace (marine terrace II). The aquifers in marine terrace II and beach has medium permeability. Porosity is formed by the cavities between the loose grains of fine to coarse sand. The water level is very shallow, ranging from 1.5 to 2 meters. There are many dug wells were made by the local people in this area which serve as the primary source of clean water. The water quality is considerably good. The water is colorless, odorless, and tasteless. The water level is slightly affected by tides. Productivity of these sandy aquifers is low. Marine terraces with loose sand sediments are found more extensive in the western part of Maratua Island overlooking the mainland of Kalimantan Island, especially in Bohebukut Village with a width of about 300 m and a length of more than 2 km. In the northern part of the island and on the inner lagoon, marine terraces with loose sand sediment are not formed. Bohe Bukut Beach can form wide loose sand because this area is a deposition area. The existence of undisturbed reefs in front of Bohebukut Beach also serves as a factor that protects the existence of sandy marine terraces that do not experience wave erosion. Therefore, aquifers in Maratua Island can be classified into three groups, namely karst aquifer, reef marine terrace aquifer, and sandy marine terrace aquifer (figure 3).

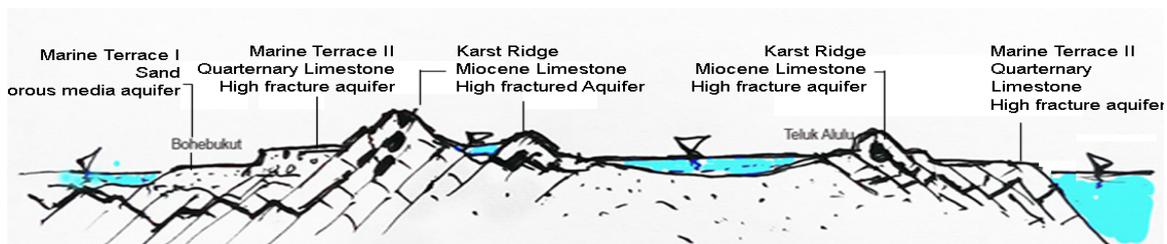


Figure 3. A Cross-Section of Maratua Island Showing a the Rocks Forming Aquifers (not to scale).

4.3. Potential for Tourist Destination Development

As a karstic island with unique landforms as described previously, the Maratua Island has enormous potential to be designated as a tourist destination (table 4.). The fringing reef situated in the outer side and inner side of the island is suitable for snorkeling, diving, swimming, and boat riding. The characteristics of the calm waves is suitable for underwater sightseeing, especially to enjoy turtle and other colourfull fish.

Table 3. Caves with Water in Maratua Island.

Nr	Cave Name	Coordinate			Water Depth (m)	Fluctuation (m)
		X	Y	Z		
1	Sembat	68067	24156	5	> 7	1.2
2	Tangkapa	67962	24247	6	< 2	0.3
3	Angkal-	67913	24282	6	-	-
4	Silandayan	67693	24442	7	> 13	1.5
5	Sipbig	67708	24418	6	> 6	1.4
6	Sukur	67475	24756	3	> 9	1.5
7	Mayat-	67455	24808	4	1	0.2
8	Pogah	67522	24689	5	< 2	0.3
9	Hapit Pogah	67518	24694	4	< 2	0.3
10	Organ	67444	24895	4	< 4	0.6
11	Jellau	67666	25343	4	> 4	1.2
12	Pahang	677,59	25190	4	> 16	-
13	Penggunting	67679	24408	4	< 3	0.5

Table 4. Tourism Activities Potential in the Landforms of Maratua Island.

No	Landforms	Tourism Activity Potential	Type of
1	Fringing Reef	Snorkeling, swimming, and diving raiding	Recreation
2	Beach	Sunbathing, sightseeing, beach sport activity	Recreation
3	Karst Ridge and Undulating karst hills	Tracking, cave exploring, rock climbing, sunset or sunrise watching	Special-Interest Tourism
4	Marine Lake	Panoramic sightseeing, rowboat	Recreation
5	Lagoon	Snorkeling, swimming, and diving, and water Games	Recreation
6	Cave	Cave exploration	Special-Interest

A beach is a landform which is closely associated with tourism. Beaches on the Maratua Island are also well known among tourists. White sand with coconut three give a breathtaking scenery along the island. Beaches can be designated as a place for sunbathing, enjoying the panorama, doing beach sports such as beach volley ball and football.

Karst ridge and undulated karst hills can be designated as a new tourist attraction. The karst right in Maratua Island are situated in the middle of the island covered by forest. Such a condition can be used to develop several types of unique interest tourism such as nature exploration/tracking or rock climbing. Steep slope of karst ridge in Maratua Island is suitable for stimulating adrenaline through out door activities such as rock climbing. Other enjoyable activity for tourists and local people in the karst hills is watching a sunrise from the top of Gunung Putih Hill.

Another special interest tourism activity that can be experienced in the island is cave exploration. The caves in Maratua Island are unique and challenging to be explored. Some of the caves are found to be watery and have a submerged passage. This situation is good for special interest tourism development in the form of cave exploration. Tourists who wish to enjoy the nature exploration in Maratua Island should have special skills in cave exploration. However, there are some caves that can be enjoyed without having to own special skills, such as Halo Tabung Cave (cenote), Sembat Cave, and Angkal-Angkal Cave.

4.4. Constrains for the Development

Maratua Island which is considered as a small island makes it has limiting conditions. Tourism development in this island should also consider those limiting factors. The main limiting factors in Maratua Island are clean water supply and limited land. Development plan should be based on the quantity and quality of these limitation. Clean water with good quality in Maratua Island is found only in aquifers in sandy marine terrace of BoheBukut.

Fulfillment of the need for clean water should get serious attention in the management of Maratua Island for tourism purposes. There are some alternatives to meet the need for water resources. One of them is by utilizing brackish water in caves and sea water distillation. The need for clean water for consumption can be met from wells in aquifers in sandy terraces. Besides, the need for clean drinking water can also be met by using rain water. The need for water for bathing and washing which do not necessarily require the use of good quality water can be met by using brackish water contained in the cave. Distilled water obtained from brackish water in the caves will reduce production coast of water purification compared to that from sea water.

Restrictions in the number of visitors and lodging development should also be considered. This has something to do with the limitation of land and the level of pollution that can be generated as a result of such development and the number of tourists that exceeds the capacity.

5. Conclusion

Maratua Island has high potential tourism development. The uniqueness of the island results in different natural attraction for tourism destination. Among the important geomorphological features are fringing reef, lagoon, beach, and caves. The potential tourism activities in the area are diving, snorkeling and boating, canoeing, caving, trekking, as well as panoramic sightseeing. However the island has limited fresh water sources and. Therefore, the island must be managed with care for tourism development. Water supply extracted from the beach area of Bohe Bukut should be limited for drinking water only. Substitutive water supply from collected rainy water or desalination from sea water should be given priority for further water supply development. The other possible water supply is from caves. Cave water can be considered for domestic water supply. Cave water can also be used as drinking water after desalinated. Desalination of cave water will be more economical than that from sea water. Restrictions in the number of visitors and lodging development should also be considered.

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