Zonation of Marine Geological Environment of Wangi-wangi Island Waters and Adjacent Area Wakatobi Districs Southeast Celebes Province

Zonasi Lingkungan Geologi Kelautan Perairan Pulau Wangi-wangi dan Sekitarnya Kabupaten Wakatobi Provinsi Sulawesi Tenggara

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ABSTRACT: Wakatobi is one of coastal and marine tourism destination in South–East Celebes Indonesia. Coastal and marine characteristics of this area is composed of diverse biota as the main tourism attraction. Unfortunately, increasing human needs and activities, particularly coral reefs exploitation for construction and other life aspect, endanger the sustainability of marine environment of Wakatobi and the surrounding area. The purpose of this study is to determine marine geology environmental zonation in Wangi–wangi–Kapota Islands, as a consideration for local government in monitoring and regulating the coastal area. The methods that were applied in this study are coastal characteristic mapping, sedimentology, and mineralogy analyses from 34 marine surface sediments. Marine surface sediments have been collected by Marine Geological Institute (MGI) team in 2014. The result indicates that coastal and marine characteristic of Wangi–wangi and Kapota are influenced by geological processes since Middle Miocene. The seafloor morphology is characterized by gentle slopes around coastline that is abruptly changed to very steep slopes seaward. In general, the surficial sediments consisted of biogenic sands that are distributed around coastlines and trapped within coral reefs. Coastal types of this area are generally white coral sand beaches, coral reef platforms, and notches. The area of Wangi–wangi and Kapota can be divided into 4 (four) environmental zone: Flat Plain (Zone I), Sandy Beach (Zone II), Limestone and Coral Reef (Zone III), and Sedimentary Flat (Zone IV). Zone IV in the centre area between Wangi–wangi and Kapota island is considered as the most vulnerable area due to both natural and anthropogenic factor.

Keywords: zonation, seafloor morphology, tourism, Wangi–wangi–Wakatobi, Southeast Celebes Province

ABSTRAK: *Wakatobi adalah salah satu tujuan wisata pantai dan laut yang menarik dikunjungi di Sulawesi Tenggara, Indonesia. Karakteristik pantai dan laut daerah ini disusun oleh keragaman biota laut yang merupakan daya tarik bagi pariwisata. Sayangnya, seiring dengan berkembangnya aktifitas dan kebutuhan manusia, terutama meningkatnya eksploitasi pemanfaatan terumbu karang untuk konstruksi bangunan dan berbagai aspek kehidupan, mengancam kelestarian lingkungan alami Wakatobi dan sekitarnya. Oleh karena itu, penelitian ini dilakukan dengan tujuan untuk membuat zonasi lingkungan pantai dan sekitarnya di Pulau Wangi–wangi dan Kapota, sehingga bisa memberikan pertimbangan bagi pemerintah setempat dalam pengawasan dan regulasi lingkungan kawasan pantai dan sekitarnya. Untuk penelitian ini, metode yang dilakukan adalah pemetaan karakteristik pantai, analisis sedimentologi dan mineralogi yang dilakukan terhadap 34 sedimen permukaan dasar laut. Pengambilan sampel sedimen permukaan dasar laut telah dilakukan oleh Tim Pusat Penelitian dan Pengembangan Geologi Kelautan (P3GL) pada tahun 2014. Hasil penelitian menunjukkan bahwa karakteristik pantai dan laut Wangi–wangi dan Kapota dipengaruhi oleh proses geologi yang telah berlangsung sejak Miosen Tengah. Morfologi dasar laut dicirikan oleh lereng landai di sekitar tepi pantai dan berubah dengan tegas menjadi curam ke arah laut lepas. Pada umumnya tekstur sedimen permukaan dasar laut terdiri atas pasir biogenik tersebar di sekitar garis pantai, dan mengisi di dalam terumbu koral. Jenis pantai sebagian besar berupa pantai pasir koral berwarna putih, pedataran pantai terumbu koral, serta morfologi pantai berupa takik. Kawasan pantai Wangi–wangi dan Kapota bisa dibagi ke dalam 4 (empat) zonasi lingkungan: Flat Plain (Zona I), Sandy Beach (Zona II), Limestone and Coral Reef (Zona III), dan Sedimentary Flat (Zona IV). Zona IV di area tengah antara Pulau Wangi–wangi dan Pulau Kapota merupakan area yang paling rentan mengalami kerusakan lingkungan akibat faktor alami dan aktifitas manusia.*

Kata kunci: *zonasi, morfologi dasar laut, wisata, Wangi–wangi–Wakatobi, Provinsi Sulawesi Tenggara*

INTRODUCTION

Wakatobi Islands consist of small islands and stand for their names, are Wangi-wangi, Kaledupa, Tongea and Binongko. It has been established as Wakatobi Marine National Park in 2002 (Crabbe *et al.*, 2004). Tourism resources of Wakatobi is one aspect contributes to the local income particularly from coastal and marine attractions including the coral reef biodiversity (Mastu *et. al*, 2018) as shown on Figure 1. Therefore, central and local governments strongly support this tourism place by developing facilities and infrastructures, promotions, and conservation of coral reefs (Purbani *et al.*, 2014). The coral reefs of Wangi-wangi are mostly moderately to well-preserved (Yulius *et al.*, 2015) and are not older than ~100 years (Crabbe, *et al.*, 2004). Coral reefs near Kaledupa is dominated by *Acropora* (Crabbe and Smith, 2002) and the coastline is characterized by mangrove (Setiadi *et al.*, 2010). Coastal and marine characteristics of Wakatobi are the result of geological processes that have been working since Middle Miocene, thus they can be used as indicator of tectonic activities in Wangi-wangi–Kapota Islands. The aim of this research is to determine marine geology environmental zonation in Wangi-wangi – Kapota Islands from its coastal and sediment characteristic.

The Wakatobi Islands are composed of reef and Quaternary sedimentary rocks (Koswara and Sukarna, 1994) that were formed by micro-continents collision. Detailed collision was summarized by Satyana (2014) as follows:

Commonly, collisions of two micro-continents will compress the oceanic crust that is lied between these two micro-continents. The oceanic crust will be distributed, forming an ophyolite trend. The collision site of two microcontinents is commonly known as a suture. If Wakatobi collide Buton, an ophyolite trend will be revealed. However, previous study indicated no ophyolite trend between these two regions, and no compression structure between Wakatobi and Buton. In contrast, collision between Buton and Muna is indicated by a Kapantoreh ophyolite trend, found in the southern part of Buton, and many compression structures found in Buton. Collision between Buton and Muna resulted dispersion of lithosphere in the Middle Miocene. The correlation between Buton and Wakatobi is considered as separation or fragmentation rather than amalgamation. Buton is the front part of the micro-continent, while Wakatobi is the tail end. Following the collision, Buton was lifted and compensated by isostatic relaxation force. Afterwards, extensional structure revealed due to the lithospheric thinning in area between Buton and Wakatobi during Middle Miocene (Figures 2).

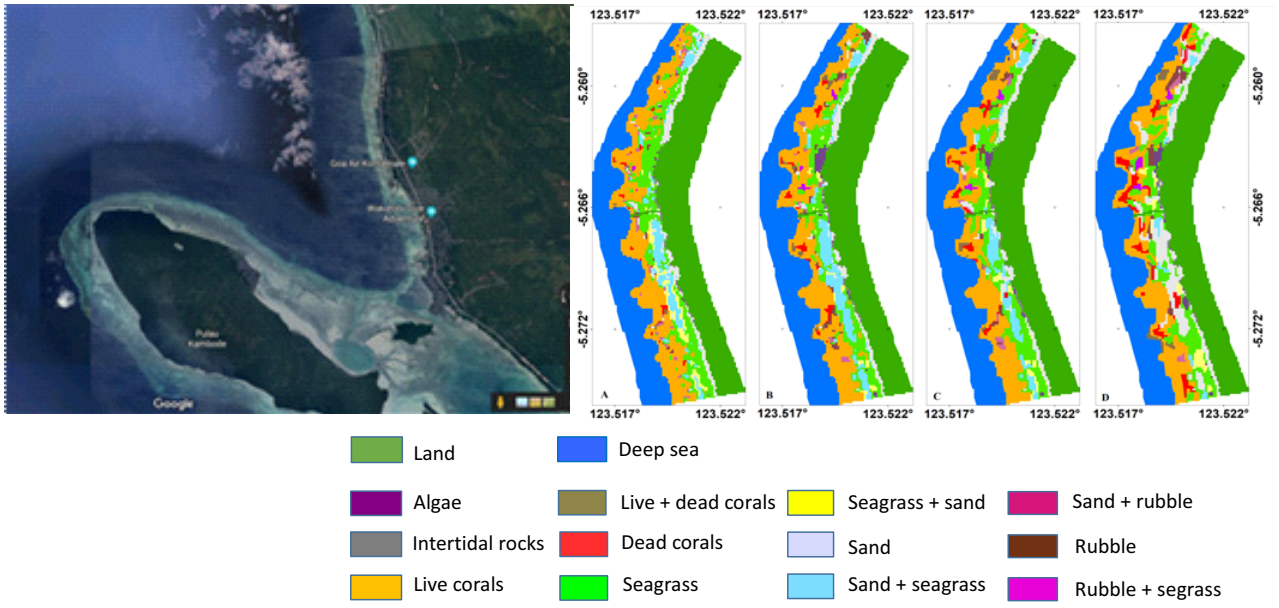

Figure 1. Satelite Image (Landsat ETM) and coral reef distribution along coast of Wangi Wangi Island (Mastu *et al,* 2018).

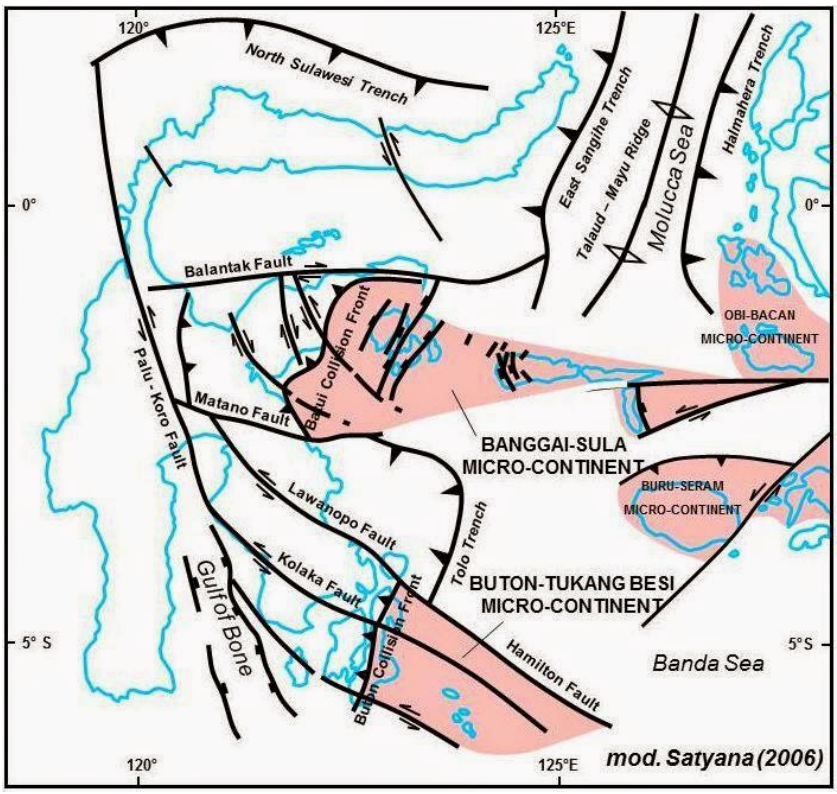

Figure 2. Modification of structure developments in Sulawesi Island (Satyana, 2014)

METHODS

This study is a part of research that has been conducted in the waters between the Wangi-wangi and Kapota island, geographically between 123°25'00"E - 123°35'00"E and 5°15'0.00"S-5°25'00"S (Figure 3), by a research team from Marine Geological Institute in 2014 (Darlan, *et. al.*, 2014). The water depth from the shoreline to 0.5 miles seaward increase gradually from 0 to 20 m, and steeply deeper afterwards (Darlan, *et al.,* 2014). Sedimentology and mineralogy were analysed from thirty four marine sediment samples, have been collected along the northeast coast of Kapota Island, and along the west coast of Wangi-wangi Island (Figure 4). Unfortunately, sediment sampling could not be conducted in the southern part of the study area due to the difficulty in accessibility. Instead of using grab sampler or other instruments, samples were retrieved by diving in order to prevent potential damage to coral reefs. From these sediment samples, sediment textures and sand size analysis was conducted based on (Folk 1980) and (Gibbs 1974). Furthermore, coastal characteristics mapping was carried out both in Wangi-wangi and Kapota Islands in order to understand the interaction between oceanographic, geologic, and anthropogenic aspects that leads to diversity in coastal morphology. Coastal characteristic mapping was conducted by observing the geological aspects, relief, shoreline characteristics and the dominant process followed the work of Dolan *et al.* (1972).

RESULTS

Sediment texture and mineralogy

Marine sediment of Wangi-wangi and Kapota is generally composed of white-brown sandy textures (weight percentage is 100%) deposited in the spaces within coral reefs. These textures cover along the coastline of western Wangi-wangi and northeast Kapota Islands and most inner side of both shelf from 0 to 40 m water depths. The grain size ranges between 0.6 to 1.2 mm, categorized as coarse to fine sand grains, with sub-rounded grain shape and well sorted grain (Figure 4, Table 1). This sediment might originated from nearby coastal rocks eroded by sea wave and current. The sediment in the north part of Wangi-wangi and Kapota Islands waters is considered thicker than that in the south part, which contained of abundant molluscs shell.

Rocks and coral reefs are distributed in the deeper sea, in the coastal slope of the waters, as the base of the sea wall in Wangi-wangi and Kapota Islands, Wakatobi regency (Figure 4). The field observation indicates that the coral reefs is in poor condition, mostly dead coral, particularly in the southern part. This might be due to

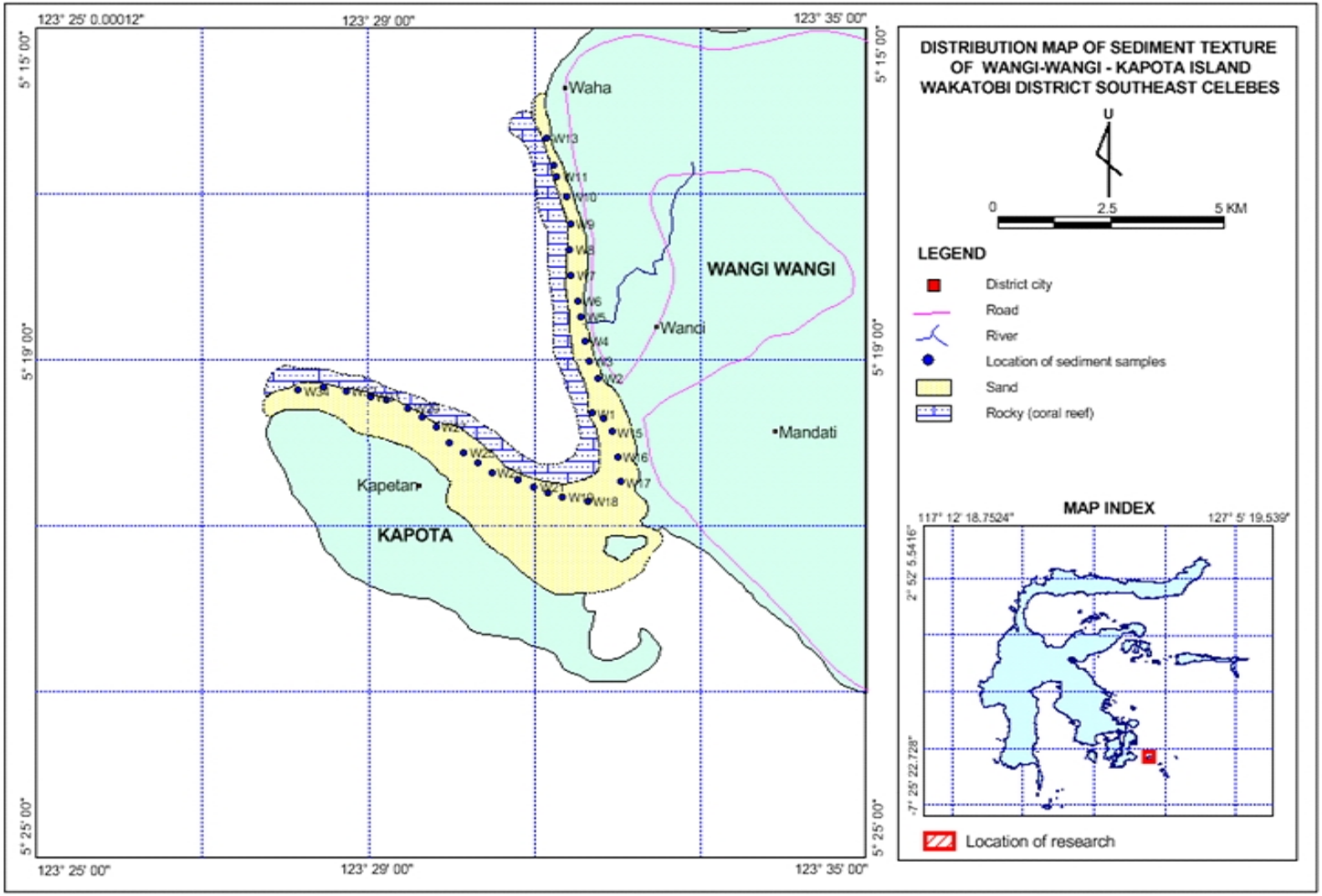

Figure 3. Bathymetry map of Wangi-wangi and Kapota (Darlan, et. al., 2014).

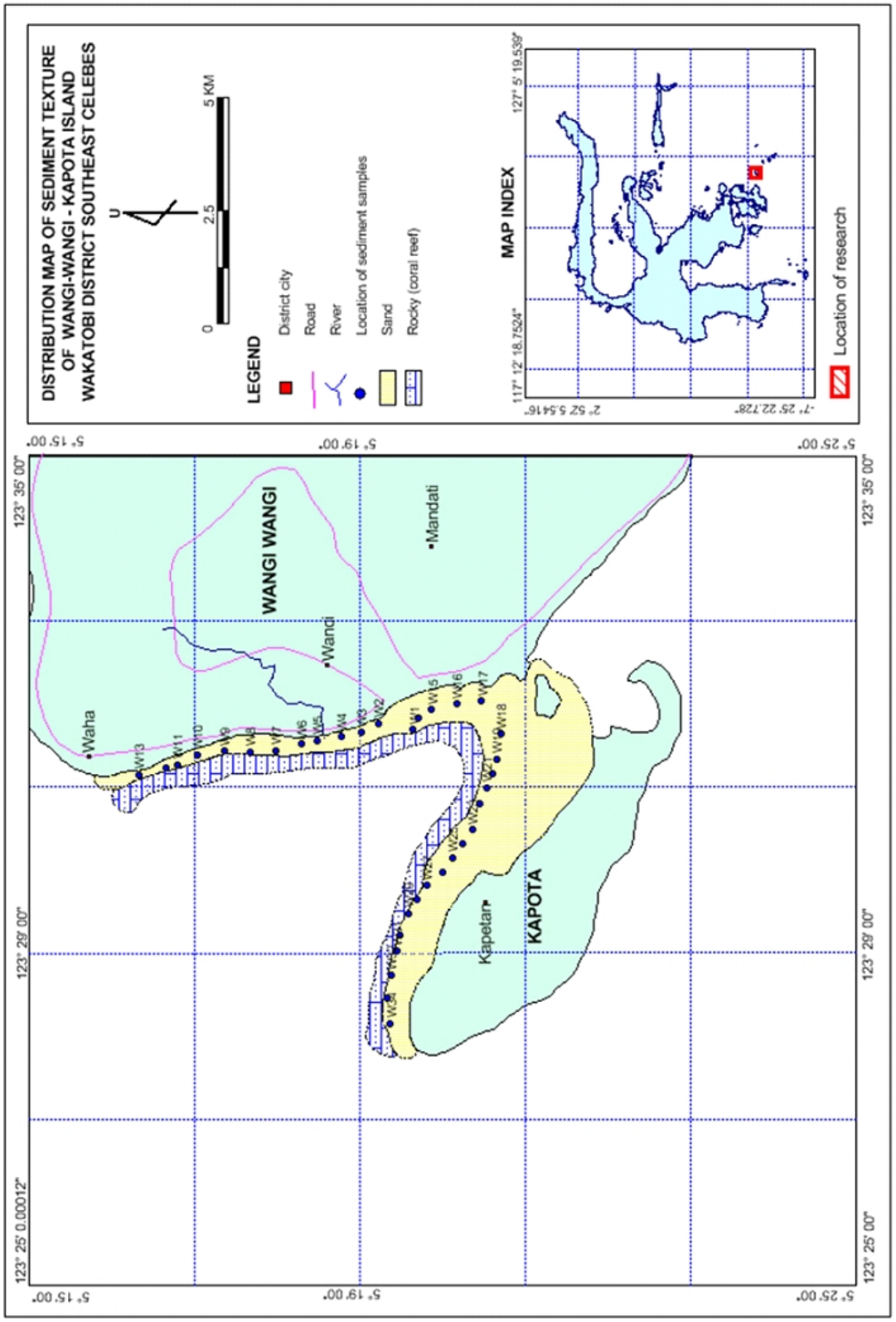

Figure 4. Distribution map of marine sediment texture of Wangi-wangi and Kapota (Darlan *et al.*, 2014)

the extremely temperature changes according to (Yulius *et al.*, 2015).

According to mineralogy analysis, most of the seabed sediment samples from southern part of Wangi-wangi and Kapota Islands composed of molluscs shell fragments and carbonate minerals with percentage >70% (Figure 5). The molluscs shells are white, yellowish white, brownish white, reddish white, and grey colours that fairly dull, irregular, and mostly consists of broken molluscs shells. The fragment of brownish white, greyish white, irregular shape, massive solid of limestone was commonly found. The iron oxide that has a reddish brown and dull coloured was rarely observed. No mafic (e.g. pyroxene) nor felsic (e.g.

Table 1. Data of grain size analyses of marine sediment forWangi-wangi and Kapota

No	Sample	Parameter of moment methods				Weigth %				Texture Class
		mean	sorting	skew.	kurtosis	gravel	sand	silt	clay	(Folk, 1968)
1	W-1	2.01	0.65	0.38	2.68	0.00	100.00	0.00	0.00	Sand (S)
2	W-2	1.78	0.98	0.28	2.01	0.00	100.00	0.00	0.00	Sand (S)
3	W-3	1.28	1.13	0.69	2.75	0.00	100.00	0.00	0.00	Sand (S)
4	W-4	1.21	1.23	0.12	2.16	0.00	100.00	0.00	0.00	Sand (S)
5	W-5	1.61	1.30	-0.13	1.79	0.00	100.00	0.00	0.00	Sand (S)
6	W-6	1.76	0.81	-0.01	2.55	0.00	100.00	0.00	0.00	Sand (S)
7	W-7	1.92	0.85	0.27	3.22	0.00	100.00	0.00	0.00	Sand (S)
8	W-8	1.51	0.84	0.13	2.70	0.00	100.00	0.00	0.00	Sand (S)
9	W-9	1.35	0.67	0.46	4.39	0.00	100.00	0.00	0.00	Sand (S)
10	W-10	1.03	0.85	0.39	2.97	0.00	100.00	0.00	0.00	Sand (S)
11	W-11	0.99	0.77	0.58	3.52	0.00	100.00	0.00	0.00	Sand (S)
12	W-12	1.00	0.71	0.39	3.47	0.00	100.00	0.00	0.00	Sand (S)
13	W-13	0.74	0.73	2.01	9.20	0.00	100.00	0.00	0.00	Sand (S)
14	W-14	1.91	1.09	-0.23	2.40	0.00	100.00	0.00	0.00	Sand (S)
15	W-15	1.65	0.96	-0.46	2.69	0.00	100.00	0.00	0.00	Sand (S)
16	W-16	1.87	0.96	0.08	2.67	0.00	100.00	0.00	0.00	Sand (S)
17	W-17	1.43	0.96	0.50	3.23	0.00	100.00	0.00	0.00	Sand (S)
18	W-18	1.76	0.84	0.04	2.30	0.00	100.00	0.00	0.00	Sand (S)
19	W-19	1.79	0.89	-0.02	2.55	0.00	100.00	0.00	0.00	Sand (S)
20	W-20	1.75	0.76	0.72	3.84	0.00	100.00	0.00	0.00	Sand (S)
21	W-21	1.45	0.88	1.04	3.62	0.00	100.00	0.00	0.00	Sand (S)
22	W-22	1.58	0.71	0.71	2.67	0.00	100.00	0.00	0.00	Sand (S)
23	W-23	1.56	1.09	0.30	2.35	0.00	100.00	0.00	0.00	Sand (S)
24	W-24	1.74	0.65	-0.04	3.72	0.00	100.00	0.00	0.00	Sand (S)
25	W-25	1.54	0.75	0.39	4.18	0.00	100.00	0.00	0.00	Sand (S)
26	W-26	1.58	0.58	-0.16	4.36	0.00	100.00	0.00	0.00	Sand (S)
27	W-27	-	-	-	-	-	-	-	-	No samples
28	W-28	0.90	0.86	1.34	5.32	0.00	100.00	0.00	0.00	Sand (S)
29	W-29	1.58	1.23	-0.52	2.31	0.00	100.00	0.00	0.00	Sand (S)
30	W-30	1.34	0.68	0.93	5.82	0.00	100.00	0.00	0.00	Sand (S)
31	W-31	1.56	0.69	-0.13	3.64	0.00	100.00	0.00	0.00	Sand (S)
32	W-32	1.02	1.10	0.39	2.74	0.00	100.00	0.00	0.00	Sand (S)
33	W-33	1.18	1.01	0.22	2.80	0.00	100.00	0.00	0.00	Sand (S)
34	W-34	1.52	0.73	0.20	3.32	0.00	100.00	0.00	0.00	Sand (S)

Figure 5. Mollusca and Carbonate fragments were generally found on marine sediments of Wangi-wangi and Kapota

feldspar, ilmenite) mineral was observed. It can be concluded that the rock of Wangi-wangi and Kapota islands waters was originated from carbonate rocks.

Coastal characteristics

Coastal typology along the west coast of Wangi-wangi and the northeast coast of Kapota Islands and their surroundings can be classified as sandy and rocky coast (Figure 6). Sandy coast has low to moderate reliefs and is dominated by marine processes. According to previous authors who have investigated this area based on GIS and geology, this coast is composed by limestone reefs, shale, and sandy limestone (Purbani *et al.*, 2014). This beach type composed of mixed characteristic of shoreline, are sand beach face and shore platform. During low sea level stand, both features can be observed, while during high tide only the sand beach face revealed. The shore platform consists of perforated coral reefs with coarse surface resulted from sea water process particularly sea erosion. Furthermore, it is common to find a notch morphology in the shoreline due to a continuous tidal erosion process. Cliff morphology is formed at the back of beach face. The beach face width ranged from 3 to 20 meters with 0° to 10° slope. The beach face sand is brownish white, pebbles to coarse sand, with rounded to sub rounded in shape and well to very poorly sorted. The main biogenic components of the sand are micrite, shell fragments, and coral fragments. Coral and sand mining was observed nearby Wangi-wangi and Kapota port that might impact the coastal environment.

According to the coastal characteristics mapping, sedimentology and mineralogy studies, study area can be divided into 4 environmental zone (Figure 7), are:

Environmental Zone I (Flat Plain)

Zone I lies along the west shoreline of Wangi-wangi and northeast coast of Kapota Islands, approximately 1 km to the seaward (< 20 m water depth). To the sea, this zone is bounded by a breaker zone, separating area with deeper water depth and coral reefs environment characteristics. To the land, the boundary is cliffs and notch (Figure 8). This zone is composed by fine - coarse sand which contained of abundant molluscs shell and limestone fragment, pebbles and limestone bed which are distributed on the sea. Those sediments are exposed during the low tide. Environmental Zone I forms the shore platform that is mostly coral reef flat that developes into low tide terraces.

The morphology of Environmental Zone I is developed by tidal erosion. The sand cover is considered as the result of erosion (by currents and waves) of the reef flat. This zone acts as a buffer to wave abrasion. The absence of river flowing to this area suggest that there is no terrigenous sediment supply to this Zone that might affect its stability and resistance to erosion. Thus, to prevent possible erosion in the future, it is imperative to prohibit coral reefs mining in this zone.

Environment Zone II (Sandy Beach)

This zone extended along the southwest part of Wangi-wangi islands extends into litoral zone (> 3 water depth). The southern boundary of Zone II is the southern tip of Kapota Island and extends to the edge of study area in the southern part of Wangi-wangi Island. The northern boundary of this Zone is defined by changes in bathymetry and seafloor sediment that forms Environmental Zone IV. Sediment characteristics in this zone is fine to coarse sand, bright white and brownish. The sand is widely spread from the shoreline to the breaker zone. The average thickness of the sand in this zone is >1 m. The morphology of this zone is similar to the previous zone, with erosion-derived sediment occurred in the southern part of the coastal area. In this zone partially formed a sand barrier which then occupied by mangroves, as a nutrition trap for marine organism (Figure 9). Field observation shows that the condition (pH, salinitas, etc) in this zone might be suitable for seaweed cultivation, regardless of sand mining that occurs in this Zone. Therefore this area is a potential place for seaweed cultivation.

Environmental Zone III (Limestone and Coral Reef)

Environmental zone III is located in the middle area between Environmental Zone I, between Wangi-wangi and Kapota Island, to the deeper part of the sea. The eastern and western borders of this zone are Wangi-wangi and Kapota islands, respectively. The boundary in the southern part is Environmental Zone IV, in the shallow waters characterized by plain morphology and coral reefs (Yulius *et al.*, 2013). The water depth in this area is deeper that 20 m, composed of limestone and coral reefs. This zone is the result of extensional processes that formed relatively deep bathymetry (approximately 200 m) that is bounded by steep slope landward. This condition is suitable for marine transportation in the deeper part and marine tourism in the slope area that is inhabited by coral reefs. The slope is popular diving spots in Wangi-wangi due to the diversity of coral reefs (Figure 10), while coral reefs in the reef flat are mostly damaged.

Environmental Zone IV (Sedimentary Flat)

This zone occupies the central part of the study area. It is bounded to the north by Zone III, to south by Zone II and shares western and eastern borders with Zone I. This zone is characterized by limestone and coral reefs, and relatively shallower water depth

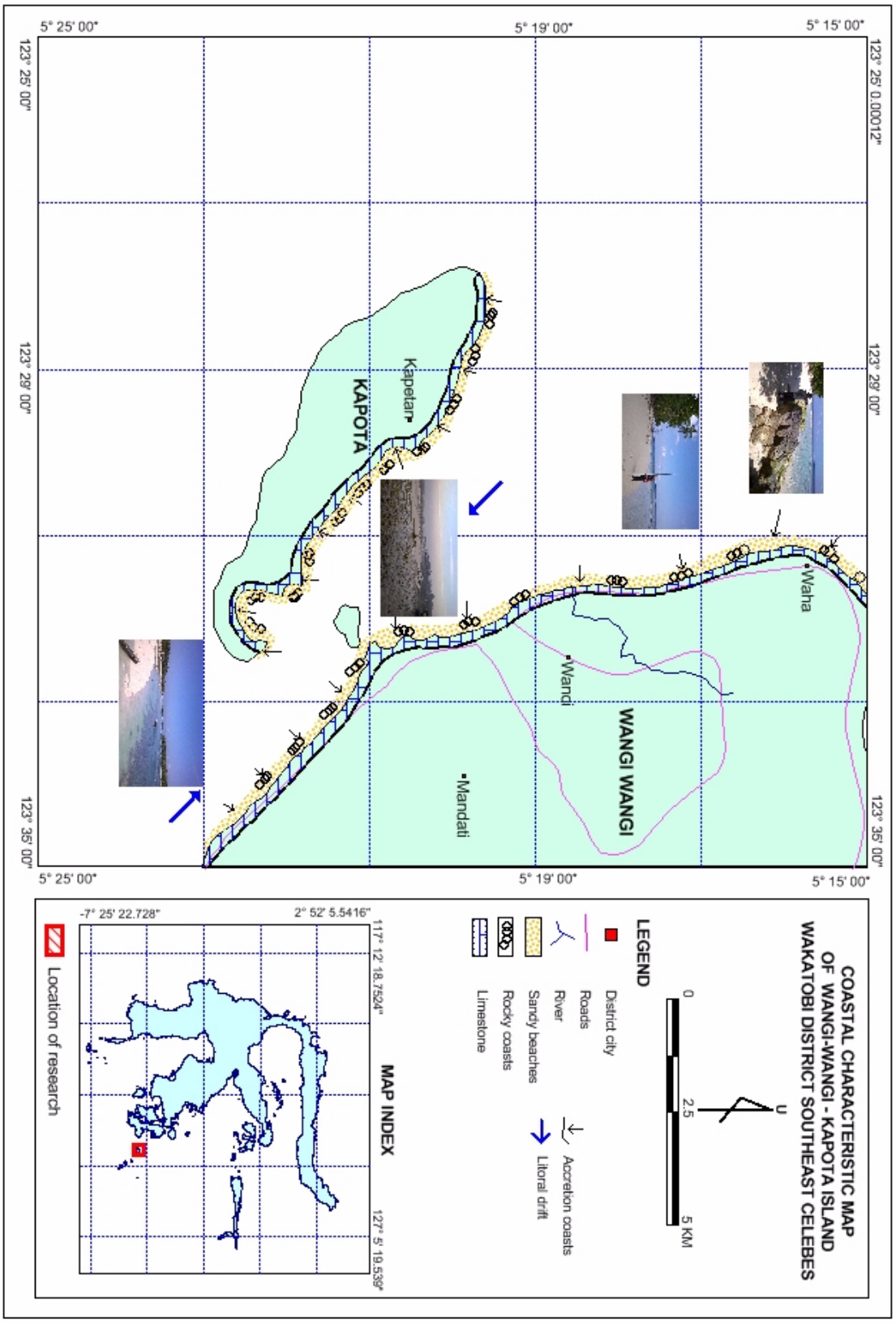

Figure 6. Coastal characteristic map of Wangi-wangi and Kapota.

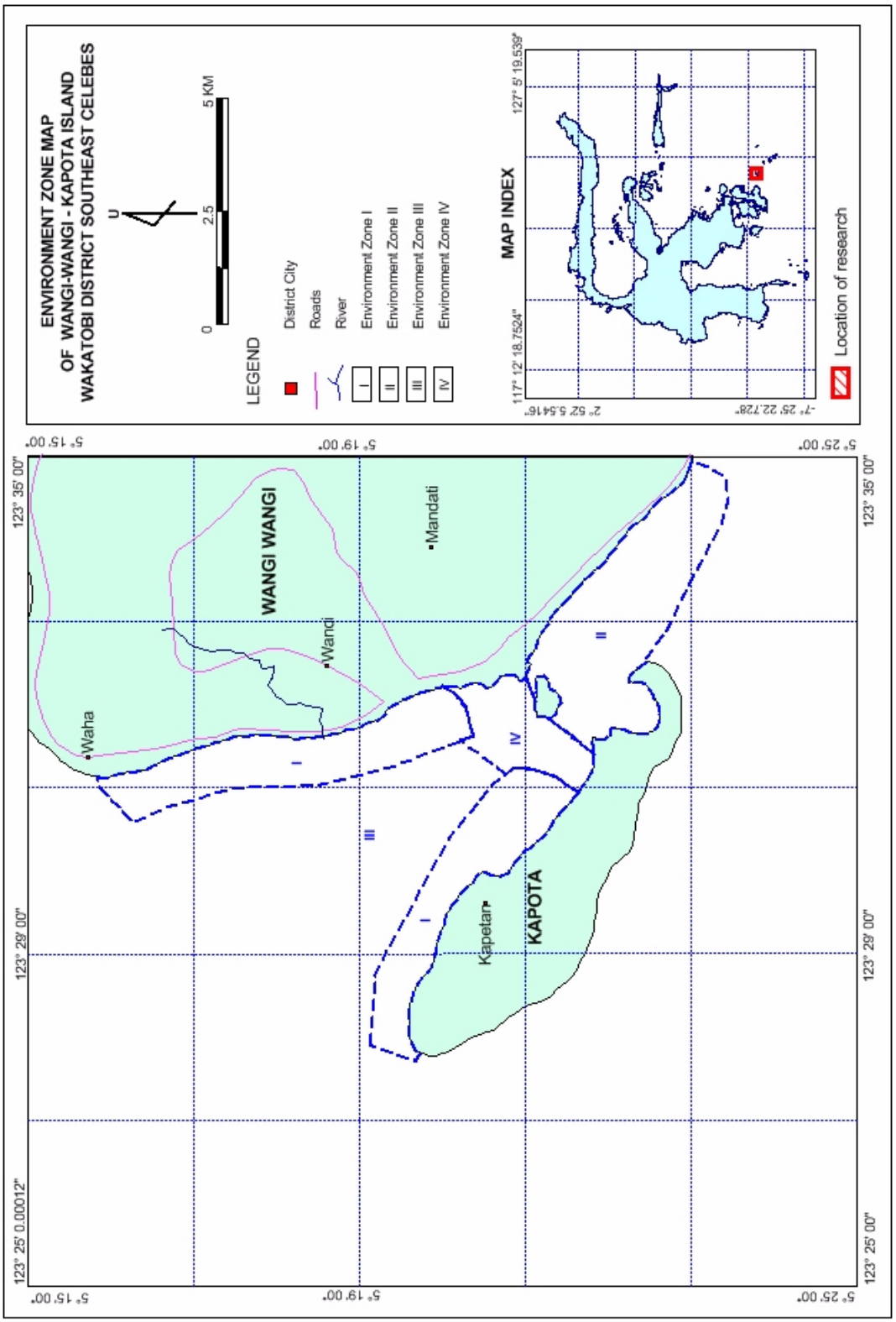

Figure 7. Environment zone map of Wangi-wangi and Kapota

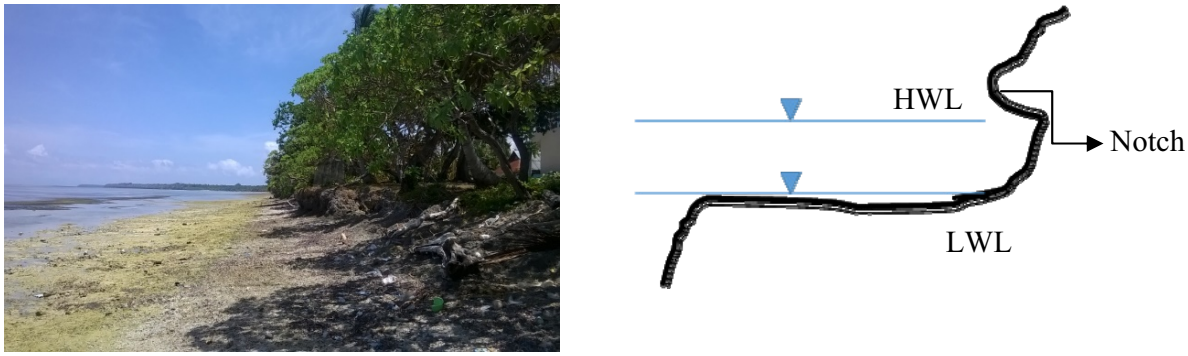

Figure 8. Flat slope typology on shoreline platform, HWL = high water level, LWL = low water level

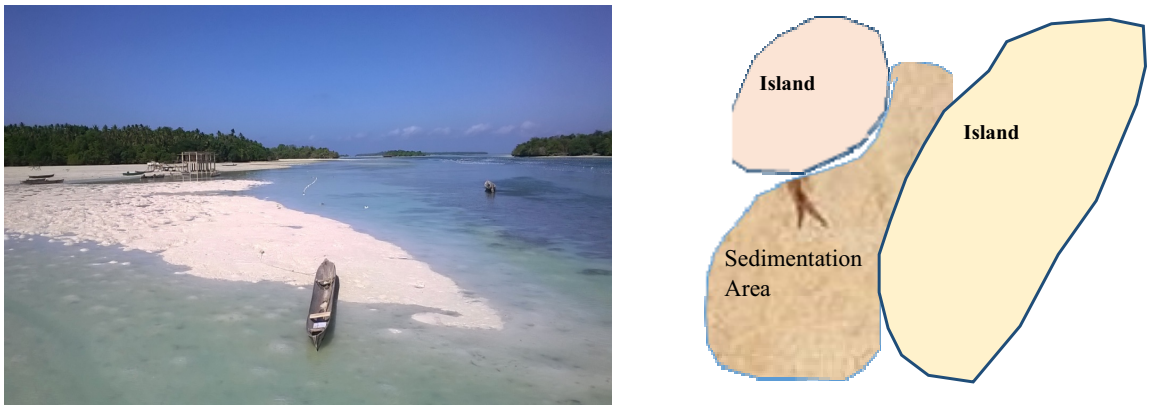

Figure 9. Sand dune and sand beach with initial mangrove growth.

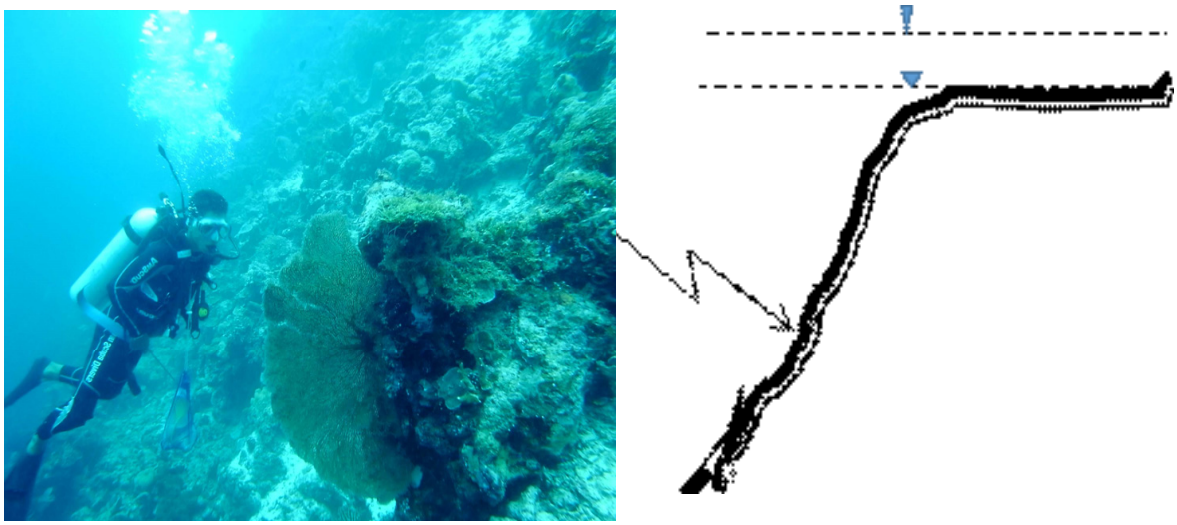

Figure 10. coral reef zone in the environmental zone III as a tourism attraction.

Figure11. Flat landscape as Bajo settlement in environment zone IV

compared to the other zones. This area is a convergence zone between two currents originated from the north and south, as a consequence, sedimentation rate at this zone is considered high, resulting a small island in the center of the waters between Wangi-wangi and Kapota islands. Given the shallow waters condition, two islands connected with a sediment bridge are revealed during low tide. The morphology of the plain in this zone is similar to that in zone I. The broad plain area in this zone leads to a development of suburban area by the Bajo settlement (Figure 11). Recently, the Wangi-wangi island is endangered by human's exploitation of limestone and coral reefs.

DISCCUSIONS

The geology of Wangi-wangi and Kapota waters that was presented by Koswara and Sukarna (1994) by combining observation on coastal, sediment, and bathymetry characteristics, indicate that the study area experiences tilting followed by a extensional process. The case that could be highlighted related to the phenomenon is the waters formation between Wangi-wangi and Kapota Islands, which was suspected developed from the extensional process. Therefore, regional geology process in Wangi-wangi and its surrounding is considered affect the primary condition of the waters such as bathymetry, sedimentation, erosion, coast characteristics, and the coral reefs formation.

Although the environmental zonation of the study area indicates 4 different environmental zone, however, according to the study of the suitability area for marine tourism of Wakatobi based on GIS application by Yulius *et al.,* (2013), almost all part along the nearshore of western Wangi-wangi and northeastern Kapota (Zone 1 and Zone IV) area defined as corresponding location, while Zone III is categorized as marginal corresponding location, a suitable location for marine tourism that need additional technology input within its development. This indicates that in general Wangi-wangi and Wakatobi is considered suitable for marine tourism. This condition is also supported by the condition of coral reef which is categorized as moderate to good condition with coverage percentage between 28–60% (Yulius *et al.*, 2015).

However, recently human activities including coral reefs exploitation are growing rapidly. This threaten the conservation of Wakatobi and need to be considered. The growing of economic and population aspect particularly occured in the western and southern part of Wangi-wangi due to its relatively shallower water depth. Therefore, Chandra *et al.* (2016) have recommended that these two areas are more suitable for economic development, while coral conservation is better to be located in the east and southern part of Wangi-wangi Island. This author also has observed that the environment in the west and northern part of Wangi-wangi has experienced degradation due to the high influence from the island, and derived from harbour development surrounding the area.

CONCLUSION

The shore characteristic of the Wangi-wangi and Kapota islands is influenced by geological process including structural geology, geomorphology, and bathymetry of the islands. The shore and sediments characteristics in this area indicate the extensional and lower tectonic processes. The environmental zonation of shore and sea in Wangi-wangi and Kapota islands based on sedimentology, mineralogy, and geomorphologic characteristics resulting in 4 different environmental zones. Environmental Zone IV in the middle area between Wangi-wangi and Kapota Island is the most endangered part of the study area due to the high sedimentation from current convergency and natural resources exploitation by human activities. It needs a good coastal management and good policy from government to manage the human activities. In addition

to the anthropogenic effect, natural process particularly current and wave influent the environmental condition resulting in both erosion and high sedimentation that also must be considered.

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