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APPLICATION OF GEOGRAPHIC INFORMATION SYSTEMS (GIS) TO DETERMINE THE STATUS OF MANGROVE ECOSYSTEMS OF MODUNG REGION MADURA

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ABSTRACT

Conversion of mangrove forests to fish ponds and settlements area has been occurred at Modung region for many years. In addition, human activities in making use of mangrove's leaves for cattle food was also a factor that could cumulatively affect the condition of mangrove ecosystems. To maintain and conserve the ecosystems, the existing condition of mangrove's area need to be assessed by employing relevant methods. Objectives of this study were to analyze the present condition of mangrove forests and to verify the critical status in the study area. Geographic Information Systems (GIS) was used in this study as a tool to analyze and to map the ecosystem status. GIS technology was employed because its ability to map the distribution of mangrove's habitat based on satellite imagery data as well as to determine its status using several criterias. According to the Landsat Imagery data, total areas of mangroves forest were 92,76 Ha. Moreover, using 2 different methods (remote sensing and field measurements), approximately 77% of mangrove ecosystems in the area can be classified as critical.

Keywords*:* *GIS, Mangroves, Modung Madura*

INTRODUCTION

Mangrove ecosystems develop on intertidal zones along tropical coastlines, such as estuaries, lagoon and deltas (Bengen, 2002). Large mangrove forests can be found along muddy sheltered shorelines free from strong winds and currents. According to Soemodihardjo (2003), there are 15 families, 18 genera and 41 mangrove species in Indonesia. Mangroves develop special adaptation systems that enable them to grow in harsh areas. Several types of the adaptation system are developed to deal with muddy substrates and lack of oxygen including their root systems (aerial root, knee root and plan root) and pneumatophores. Some mangroves species also develop secreting organs (salt gland) to handle high salinity and evaporation condition (Nybakken, 1992).

Mangrove ecosystems are acknowledged to have important functions in supporting coastal fisheries. Robertson and Duke (1987) *cited in* Long and Skewes (1996) state that mangroves provide habitat and nursery zones for commercial pelagic fish and crustaceans. They also play important roles in shoreline protection and reduce the devastating impact of tsunamis and hurricanes (Chatterjee, 2006). Other essential functions of mangrove ecosystems include maintaining water quality, buffering toxic chemical substances from inland industries and as reservoirs of genetic materials (Long and Skewes, 1996; Giri *et al.*, 2007).

Mangrove vegetations protect the shoreline from devastating waves, storm and tsunami. There are strong correlation between the existence of mangrove forests with the impact of tsunami waves in Thailand and Sri Lanka, during the 2004 Aceh earthquake. Areas with thick mangrove forests experienced significantly minor impact compared with areas where mangrove forests were absent (Hidayah, 2007).

Regardless of the significant ecological functions, however, mangrove ecosystems are declining at a shocking rate. It is estimated that mangrove stands around the globe declined from 16,361,000 Ha in 1990 to 14,653,000 Ha in 2000 (FAO, 2004). This rapid decline is caused by extensive coastal developments, expansion of human settlement and the impact of natural disasters. Evidences of extensive mangrove degradation in many coastal regions of the world have been widely documented. Forbe *et al.* (1996) reported a decline of mangrove forest area through sedimentation, and dredging in Kwazulu-Natal, South Africa. A study done in Thailand by Akosornkoae and Paphavasit (1996), has documented an extensive damage to its mangrove ecosystem due to sea level rise.

Related problems were also found by Nur *et al*. (2001) in Indonesia, especially at Jakarta Bay and the North Coast of Java Island. Over 70 percent of Indonesia's remaining mangrove forests are damaged due to human activities. The forestry ministry data shows about 6.7 million of Indonesia's 9.4 million hectares of mangrove forest are damaged, including 2.2 million of which are seriously degraded. The figures do not include mangrove forest that has been cleared or converted for agriculture (Maulana and Syafitri, 2004).

Remote sensing offers many advantages in the assessment and monitoring of mangrove studies. Giri *et.al* (2007) emphasize that, although remote sensing can not completely replace field measurement, it provides extensive supplementary information. Recent studies in the literature revealed an extensive application of remote sensing and GIS in mapping and assessing mangrove ecologies using various types of satellite images along the coastal regions worldwide. For instance, an assessment of mangroves area using Landsat Thematic Mapper (TM) 5 in Santiago River of West Mexico by Ramirez-Garcia *et a.l* (2008).

Therefore, to overcome further degradation of mangrove ecosystems, an effective and continuous study on existing mangrove condition is important. There were not many studies on mangrove in Madura ever conducted. A research conducted by Khomsin (2005) attempted to determine a conservation zone of mangrove ecosystems in Sampang district. Although this research was successfully detect the change of mangrove forests using satellite imagery data, the conclusion on conservation zone of the study was made based only on the level of human activities, sediment fertility and some others simple criteria. The use of GIS as a decision support system in the study was not clearly explained and utilized.

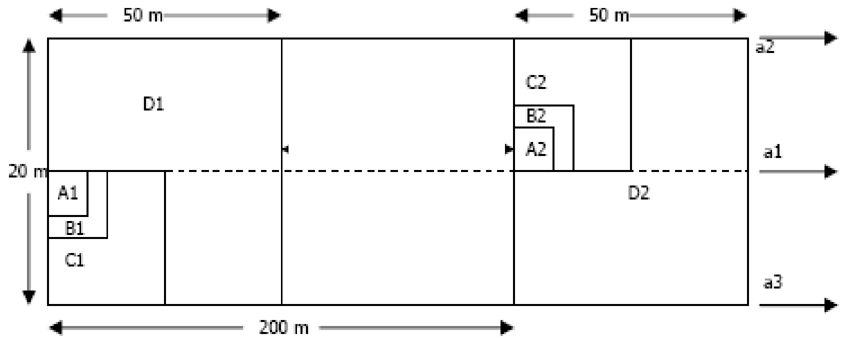
The objectives of this study were to map and analyze the current condition of mangrove ecosystems on the study area as well as to determine the status of the ecosystems using several criteria. The criteria that are used in this study were more complex, because it combined data from satellite imagery data, field measurement and social economic factors from local residents. In order to analyze the data, this study employed Geographic Information Systems (GIS) as the main tool. This technology was chosen because its ability to create a spatial database as well as to analyze the ecological data and to visualize the result as thematic maps (Moloney, 2007).

MATERIALS AND METHODS

This study was conducted at Modung region, around 37 kilometers to the East of Kamal harbour Madura. Observation and data collection was done from January to June 2013 at six locations. Quadratic transects with various size was used to facilitate determination of number and mangroves species as well as bio-physics parameters of the study area (Figure 1).

Several types of data from different sources were collected for this study. The mangrove and its environmental condition including mangrove species, water quality and sediment were one of the main inputs. Another important data collected for this study was the 1:25.000 basic map of the study area. This map was obtained from the National Mapping and Survey Agency (Bakorsurtanal) and contained important geographic features, such as administration boundaries, coastlines and land use. Finally, a Landsat ETM/7 Satellite Imagery data was utilized to detect and measure mangrove coverage areas. To analyze and visualize the data, two important softwares (ArcGIS 9.1 and ENVI 4.4) were employed. Further mathematical analysis was done using Microsoft Excel.

To asses the level of mangrove critical condition of the study area, 3 analyses were made. A satellite imagery data analysis was conducted to determine the mangrove coverage area. Furthermore on-site surveys were conducted to determine mangrove species and its physical condition and finally a social-economic survey was performed to obtain important information from local people on mangrove's exploitation of the area. Each of analyses was then used to categorize the level of mangrove's critical condition using some criteria. These criteria were developed from The Manual of Mangrove Survey published by The Department of Forestry (2005). The critical evaluation of mangrove ecosystems of the study area and its categories can be seen in Table 1.



C-1: 10 x 10 meters transect B-1: 5 x 5 meters transect A-1: 2 x 2 meters transect

Figure 1. Transects Design Used for the Study

RESULTS AND DISCUSSION

There were 3 main parameters observed during the study, including salinity, ph and water temperature. The results showed that salinity in the study area ranged from 23 – 27 ppm. This feature was lower than general sea water salinity which usually above 30 ppm. It happened because there were fresh water inputs from a river which close to the study area. The results also identified that the average of water temperature was not fluctuate ranged from 27 – 31^{0}C. Within this range of temperature, mangrove vegetation can grow effectively (Kusmana, 2003). According to Maulana and Syafitri (2004), mangrove vegetations grow well in water environment with pH ranges from 5 – 9. The ph of the study area vary from 7.4 – 7.7, therefore based on the pH measurements, the study area was suitable as a habitat for mangrove vegetations.

According to the remote sensing analysis, 6 villages of the Modung region have mangrove ecosystems with different size of areas. The total areas of mangrove forest at Modung region was approximately 92,76 Ha. The mangrove area was calculated using a Landsat ETM/7 imagery by means of supervised classification with overall accuracy of 95,103%. Total area of mangrove forest for each site can be found in Table 2.

Species which found along the study including *Rhizopora mucronata, Rhizopora apiculata, Sonneratia alba* and *Avicennia marina*. To calculate the domination of each species, the INP index was applied. The result showed that *Sonneratia alba* was more dominant compare to other vegetations (average INP index 129,73). Furthermore, according to the calculation using satellite imagery data, NDVI value of mangrove ecosystems of the study area ranged from -0.64 to 0.25, and can be categorized as sparse to dense coverage (Hidayah and Muhsoni, 2009).

Table 1. The Critical Evaluation of Mangrove Ecosystems Using Several Criteria

No	Methods	Classification	Score	Weight
1	Critical evaluation based on remote sensing data	- Land Use (LU) :		
		1.Mangrove forest	3	
		2.Mix forest	2	45
	Total Score = (LU x 45)+(NDVI x 35)+(SU x 20)	3.Mix with urban areas	1	
	Categories by score :	- Mangrove Coverage and Density (NDVI)		
	Total Score 100-166 : heavily damaged	1.70-100% coverage (0,43<NDVI<1,00)	3	
		2.50-69% coverage (0,33<NDVI<0,42)	2	35
	Total Score 167-233 : damaged	3.< 50% coverage (-1,0<NDVI<0,32)	1	
	Total Score 234 – 300 : reasonably good	- Substrates (SU)		
		1.Mud and clay	3	
		2.Mix (mud, clay and sand)	2	20
		3.Sand and gravel	1	
2	Critical evaluation based on on-site surveys	- Land Use (LU) :		
		1.Mangrove forest	5	
	Total Score = (LU x 30) + (NU x 25) + (GB x 30) + (AR x 15)	2.Mangroves mix with other vegetations	4	30
		3.Mangrove forest surrounded by fish ponds	3	
	Categories by score :	4.Mangrove forest located nearby urban areas	2	
	Total Score 100 -200 : heavily damaged	5.Unvegetated areas	1	
	Total Score 201-300 : damaged	- Number of mangrove vegetations/Ha (NU)		
		1. > 2000 vegetations/Ha	5	
		2.1500-2000 vegetations/Ha	4	
	Total Score > 300 : reasonably good	3.1000-1500 vegetations/Ha	3	25
		4. 500-1000 vegetations/Ha	2	
		5. < 500 vegetations/Ha	1	
		- Mangrove green belt thickness (GB)		
		1. 100% (130 x tidal range)	5	
		2. 80% - 100% (130 x tidal range)	4	30
		3. 60% - 80% (130 x tidal range)	3	
		4. 40% - 60% (130 x tidal range)	2	
		5. < 40% (130 x tidal range)	1	
		- Abrasion rate (AR)		
		1. < 1 meter/year	5	
		2. 1-2 meters/ year	4	15
		3. 2-3 meters/year	3	
		4. 3-5 meters/year	2	
		5. > 5 meters/year	1	

Table 2. Mangrove Area of Each Site

No	Site's Name	Coordinate		Mangrove Area (Ha)
		North	East	
1	Desa Karang Anyar	07^o.11'.07"	112^o.55'.03,1"	39.76
2	Desa Modung	07^o.11'.19"	112^o.55'.39,6"	21.31
3	Desa Suwaan	07^o.11'.29,5"	112^o.56'.42,9"	0.93
4	Desa Langpanggang	07^o.11'.37,9"	112^o.57'.16,5"	22.43
5	Desa Patengteng	07^o.11'.58"	112^o.58'.46,3"	6.52
6	Desa Pangpajung	07^o.12'.09,5''	112^o.59'.32,2"	1.81
			Total	92.76

Moreover, substrate analysis was also conducted during the study. The results revealed that most of the mangroves ecosystem of the study area was dominated by sand (percentage > 70%) and mixed between mud and clay (Figure 3). Sand dominated substrate is considered prone to abrasion due to strong waves and current compare to substrate with high percentage of mud and clay (Parnell, 2008). Although the size of sand particle is bigger, the bound between particles is not as strong as mud and clay. Therefore, the wave energy could easily move sand particles and results on abrasion.

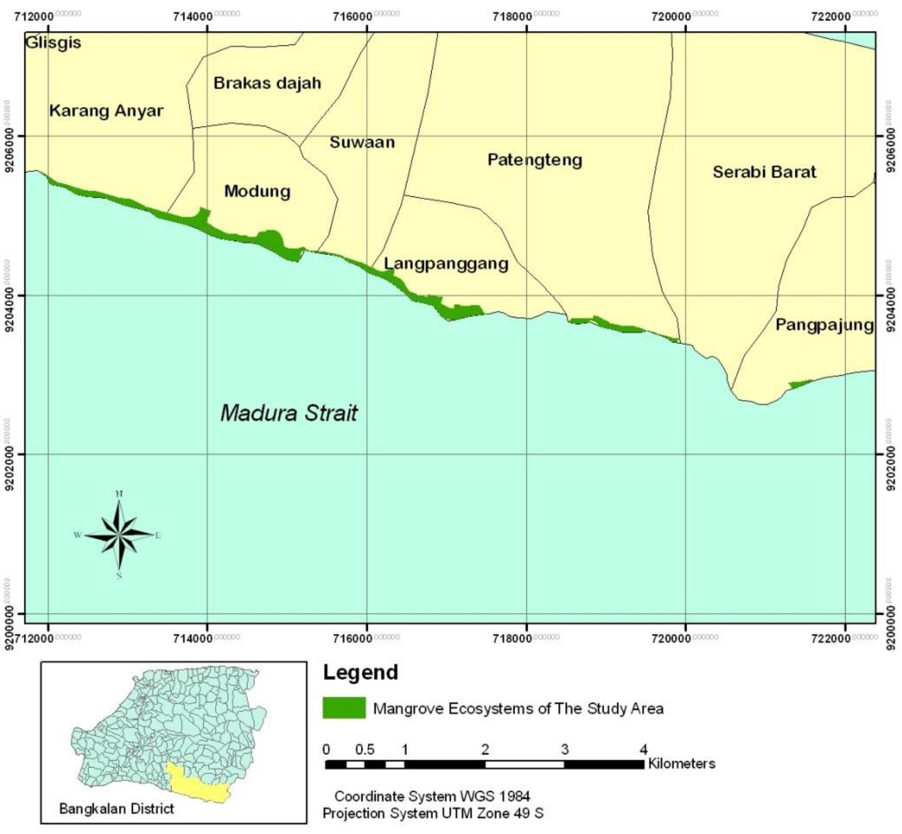


Figure 2**.** Map of Mangrove Ecosystems of the Study Area (Results of Landsat ETM/7 Analysis)

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Table 3. NDVI Values of Mangrove Ecosystems on Each Site

No.	Site's Name	NDVI Value	Type	Substrates
1.	Karang Anyar	-0.573	Mangrove Forest	Sand
2.	Modung	-0.640	Mangrove Forest	Mix (Mud and Clay)
3.	Suwaan	0.091	Mangrove Forest	Mix (Mud and Clay)
4.	Langpanggang	0.253	Mangrove Forest	Sand
5.	Patengteng	0.067	Mangrove Forest	Sand
6.	Pangpajung	-0.432	Mangrove Forest Associated With Urban Areas	Mix (Mud and Clay)

The three analyses were than combined to produce a critical evaluation of the mangrove ecosystems. Table 4 below describes the total score of each site based on criteria from the Department of Forestry as it explained in Table 1. Mangroves forest at all observation sites were categorized as critical. The status mainly contributed by the NDVI value. From the previous explanation, based on NDVI all mangrove ecosystems in the study areas can be classified as in the sparse condition. It means that, the area were lack of mangrove coverage.

Furthermore, data analysis from on-site observation showed slightly different results. As it explains previously, the critical evaluation with this method is using different criteria, such as: association with other vegetations, number of vegetations/Ha, green belt thickness and abrasion rate.

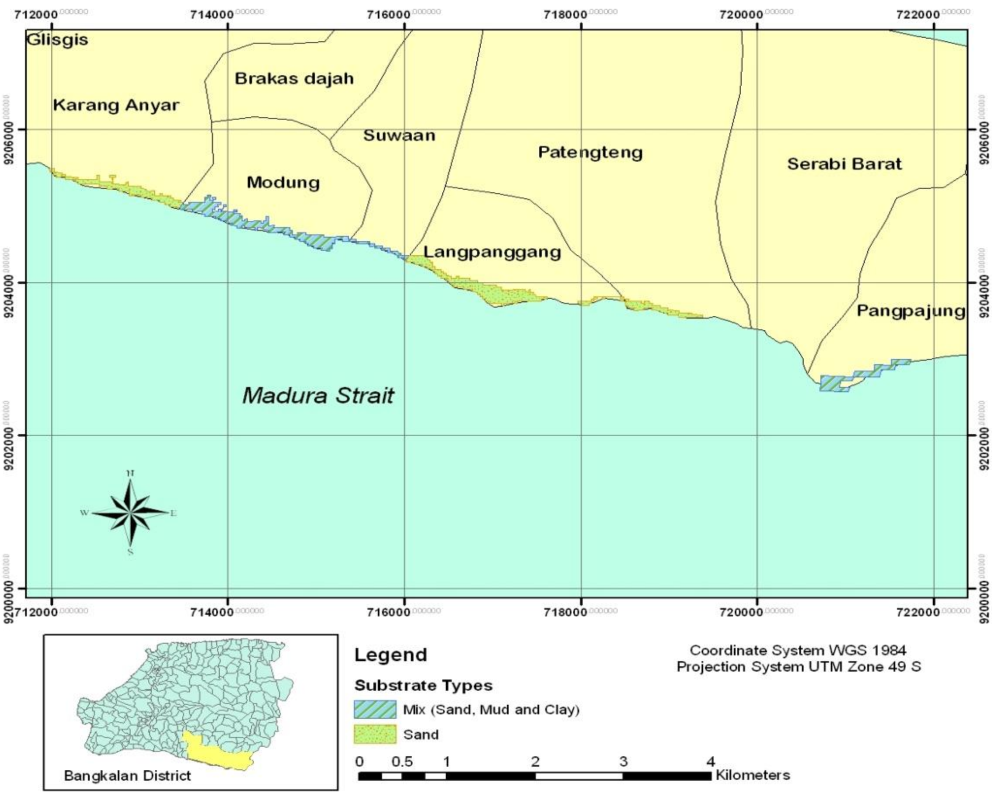

Figure 3. Map of Substrates Types of the Study Area

Table 4. Critical Evaluation of Mangrove Ecosystems of the Study Area

Site's Name	NDVI Score	Land Use Score	Type of Substrates	Total Score	Categories
Karang Anyar	35	135	20	190	Damage
Modung	35	135	40	210	Damage
Suwaan	35	135	40	210	Damage
Langpanggang	35	135	20	190	Damage
Patengteng	35	135	20	190	Damage
Pangpajung	35	45	40	210	Damage

All mangrove ecosystems on the study areas were not detached, but they were associated with other vegetations. Most of these vegetations were inland trees, flowering shrub and grass. This condition occurred, because mangrove ecosystems of the study area were located not on river's delta, but at the edge of the mainland. In addition, the similarity between types of substrate was considered to be a factor that makes inland vegetations could grow mutually with mangroves. Moreover, 4 observation sites (Modung, Suwaan, Langpanggang and Karanganyar) had less than 1000 trees/ Ha and only 2 sites (Patengteng and Pangpajung) had approximately 1500 trees/Ha (Table 5).

Moreover, there were variations of the thickness of green belt on the sites. The thickest green belt was located at Patengteng site (214 meters), in contrast the less thick green belt was only 37 meters located on Pangpajung site. The thickness of green belt was than compared to the tidal range of the locations which approximately 1,7 meters (Table 6). Abrasion rate on each site was also different. At several locations, abrasion rate reached 1 meters/ year while at the other locations, abrasion was not detected (Table 6).

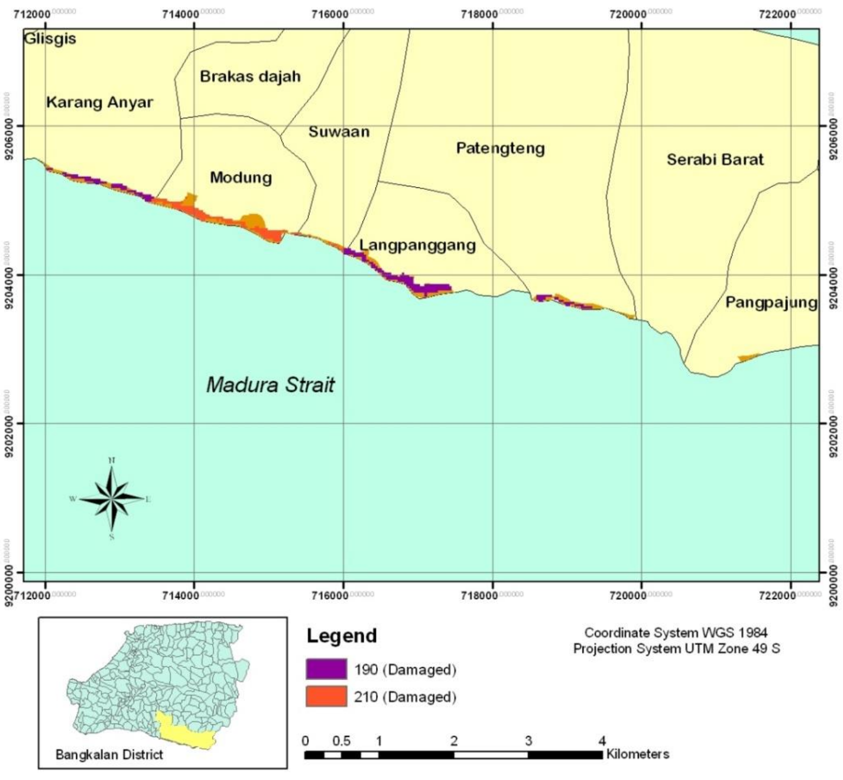

Figure 4. Results of Mangrove Critical Evaluation of the Study Area

Table 5. Mangrove Ecosystems Condition Based on Field Surveys

Site's Name	Association With Other Vegetations	Number of Trees/ Ha
Karang Anyar	Mix with other vegetations	< 1000
Modung	Mix with other vegetations	< 1000
Suwaan	Mix with other vegetations	< 1000
Langpanggang	Mix with other vegetations	< 1000
Patengteng	Mix with other vegetations	± 1500
Pangpajung	Mix with other vegetations	± 1500

Table 6. Comparison of Green Belt Thickness and Abrasion Rate

Site's Name	Green Belt Thickness (m)	130 x Tidal Range (m)	Percentage (%)	Abrasion Rate (meters/year)
Karang Anyar	150	221	67,87	0-1
Modung	127	221	47,46	No abrasion
Suwaan	162	221	73,30	0.5
Langpanggang	185	221	83,71	No abrasion
Patengteng	214	221	96,83	0-1
Pangpajung	37	221	16,74	0-1

Table 7. Critical Evaluation of Mangroves Ecosystems Based on Field Observations

Site's Name	Scores Association with Other Vegetations	Scores Number of Trees/ Ha	Scores % of Green Belt Compare to Tidal Range	Scores Abrasion Rate	Total Score	Categories
Karang Anyar	60	50	90	60	260	Damaged
Modung	60	50	60	75	245	Damaged
Suwaan	60	50	90	75	275	Damaged
Langpanggang	60	50	120	75	305	Good
Patengteng	60	75	120	60	315	Good
Pangpajung	60	75	30	60	225	Damaged

The results showed that over 77,17% of mangrove ecosystems of the study areas were under critical conditions. The main factors that produce the condition were the utilization of mangrove leaves for cattle food and sand mining. Although mangrove vegetations could regenerate their leaves and timbers, it still needs a sufficient recovering time. When the rate of mangroves leaves exploitation higher than their recovering time, the ecosystems might not be able to restore. Furthermore, if the exploitation continues in daily basis, the existences of the ecosystems are under a serious threat.

Sand mining was also a serious problem for the ecosystems. Local people exploit sand from mangrove forest as materials to build houses. Even tough mangroves have unique root systems that make them capable to grow on soft substrates, rapid exploitation of the sediment could easily destroy the ecosystems. Local people usually cut the root to make them easier to accumulate the sand before it transported to the land. As the root damages, the ability of mangrove vegetations to absorb oxygen and nutrient is lost and as the consequences, the vegetations might lost their ability to grow and die.

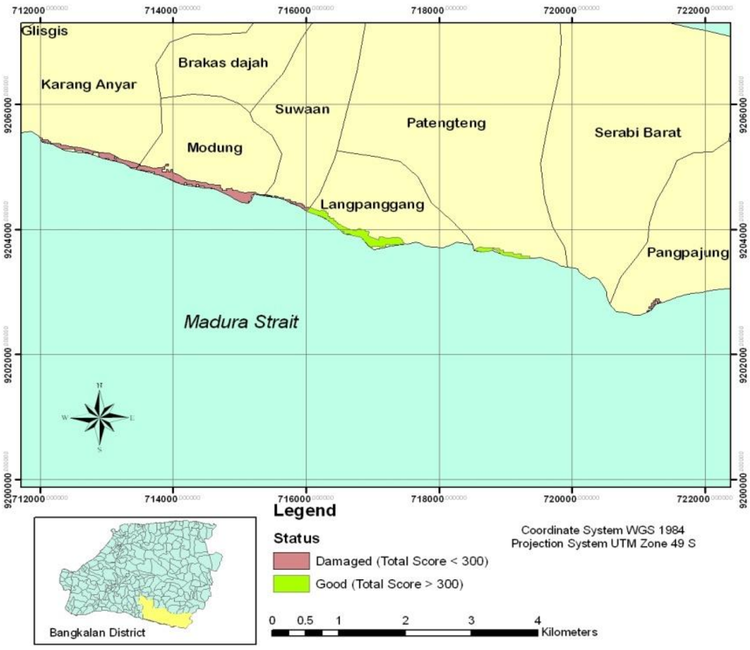

Figure 5**.** Results of Mangrove Critical Evaluation of the Study Area Based on Field Surveys

CONCLUSIONS AND SUGGESTIONS

This study has provided an example of a simple GIS analysis to understand ecological status of mangrove ecosystems. According to this study, mangroves ecosystems can be found at six sites. The ecosystems consist of several species including *Rhizopora mucronata, Rhizopora apiculata, Sonneratia alba* and *Avicennia marina*. Results of the critical evaluation using two methods showed different findings. Observations using remote sensing data revealed that status of mangrove ecosystems on all sites was critical, whereas according to on-site observation, 2 sites have a reasonably good condition. It can be argued that the differences occur because criteria which used in the methods were different. However, this study has shown the ability to map and analyze mangroves ecosystem data using GIS technology. Because the study area was relatively narrow, it is recommended to use the same methodologies to determine mangroves condition at larger areas.

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