Reconstruction of Maritime Boundary between Indonesia and Singapore Using Landsat-ETM Satellite Image

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Key words: Reconstruction, Maritime Boundary Delimitation, Landsat ETM Satellite Image

SUMMARY

State boundaries are the main manifestation of a country sovereignty. Up to now, Indonesia has still unresolved its maritime boundary with 10 countries. The certainty of the state boundary has to be declared using a chart with an adequate scale or using geographical coordinates describing the real condition of the area which specifies the geodetic datum. There are many technologies to determine these maritime boundaries, one of them is remote sensing technology. This research focuses on baseline reconstruction as the reference in maritime delimitation as defined by UNCLOS using Landsat ETM satellite image and investigate the delimitation of Indonesia and Singapore as case study. Since the baseline uses the low water line, this research assumed that boundary of land and water body shown in the image is the low water line. So far the result of this research shows that the combination of Image Enhancement and Image Classification method could be used to identify the baseline.

INTISARI

Perbatasan wilayah negara merupakan manifestasi utama kedaulatan wilayah suatu negara. Batas wilayah mempunyai peranan penting dalam penentuan batas kedaulatan, pemanfaatan sumber daya alam, menjaga keamanan dan keutuhan wilayah. Hingga saat ini, perbatasan maritim Indonesia dengan 10 negara tetangganya belum seluruhnya selesai, artinya batas kedaulatan Indonesia belum jelas. Untuk itu kepastian hukum dan batas kedaulatan Indonesia yang diwujudkan dalam bentuk peta dengan skala yang memadai atau daftar koordinat geografis perlu segera diselesaikan. Salah satu alternatif teknologi yang dapat dimanfaatkan untuk penentuan batas maritim suatu negara adalah dengan menggunakan teknologi penginderaan jauh. Penelitian ini memanfaatkan teknologi penginderaan jauh dalam penentuan batas maritim negara yang difokuskan pada penentuan garis pangkal sebagai acuan penarikan garis batas maritim berdasarkan UNCLOS memanfaatkan citra satelit Landsat ETM dengan studi kasus batas maritim antara Indonesia dan Singapura. Menurut UNCLOS garis pangkal menggunakan garis air rendah, dalam hal ini batas darat dan air yang tergambar pada citra diasumsikan sebagai garis air rendah. Hasil penelitian yang dilakukan menunjukkan bahwa kombinasi dari metode Penajaman Citra menggunakan Komposit RGB serta *Rationing*, dan metode Klasifikasi Citra menggunakan *Density Slicing* serta Klasifikasi Terawasi, dapat digunakan dalam penentuan batas darat dan air yang selanjutnya ditetapkan sebagai garis pangkal.

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1. INTRODUCTION

Indonesia has ratified the United Nations Convention on the Law of the Sea (UNCLOS) signed at 30 April 1982 by the Act No. 17 of 10 December 1985. UNCLOS is a significant agreement providing international conditions and limits concerning the use and exploitation of the earth's oceans. Included in UNCLOS are rules on how member states define their maritime jurisdictional boundaries. As consequence, Indonesia has to give charts or lists of geographical coordinates to the Secretary General of the United Nations. The Territories of the Indonesian Waters comprise of the Indonesian territorial sea, the archipelago waters and the inland waters.

The Act on Indonesian Waters of 1996 has changed some of Indonesia's baselines, but unlike its predecessor, Law No. 4 of 18 February 1960 did not provide a list of coordinates; it only included a provisional illustrative map valid until maps with adequate scale and lists of geographical coordinates were more available. Indonesia promulgated Government Regulation No. 61 of 1998 on the list of geographical coordinates of the archipelagic baselines of Indonesia in the Natuna Sea on 16 June 1998, and then Government Regulation No. 38 of 28 June 1998 on the list of geographical coordinates of the archipelagic baselines of Indonesia revoked the previous Government Regulation. This last regulation is still not the final decision of the Indonesia's baselines.

Indonesia claimed a 12-nautical-mile territorial sea, measured from baselines; a 200-nautical-mile Exclusive Economic Zone (EEZ), and the continental shelf to the depth of exploitation. These claims in several parts overlapped the claims of Malaysia, Singapore, the Philippines, Vietnam, Papua New Guinea, and Australia. The Government of Indonesia has taken the lead in negotiating acceptable common boundaries with certain of its neighbors. Up to now, Indonesia has still unresolved its maritime boundary with 10 countries. Table 1 give the information about Indonesia's maritime boundaries.

There are many technologies to determine these maritime boundaries; one of them is remote sensing technology. This research focused on baseline identification as reference in maritime delimitation based on UNCLOS using Landsat ETM satellite image and took the delimitation of Indonesia and Singapore as case study. Since the baseline uses the low water line, this research assumed that boundary of land and water body shown in the image is the low water line.

Table 1: Indonesia's maritime boundaries (LPPM, 2004)

No.	Neighbor Countries	Indonesia		
		Territorial Sea	**EEZ**	**Continental Shelf**
1.	Malaysia	Half Resolved	Unresolved	Unresolved
2.	Singapore	Half Resolved		
3.	Philippine	Unresolved	Unresolved	Unresolved
4.	Thailand		Unresolved	Solved
5.	Vietnam		Unresolved	Solved
6.	India		Unresolved	Solved
7.	Papua New Guinea	Solved	Unresolved	Unresolved
8.	Palau		Unresolved	Unresolved
9.	Timor Leste	Unresolved	Unresolved	Unresolved
10.	Australia		Solved	Solved

2. DATA AND STUDY AREA

The data used in this research is shown in Table 2, while the study area is shown in Figure 1.

Table 2: Data

Type of Data	Date	Source
Landsat-7 ETM Image, *Band* 1,2,3,4,5,7	2 April 2002	LAPAN
Indonesia Archipelagic Baseline Charts in Natuna Sea, Malaka Gulf, and Singapore Gulf, Scale 1:200.000	1999	BAKOSURTANAL

The Indonesia-Singapore territorial sea boundary consists of three segments. The Government of the Republic of Indonesia and the Republic of Singapore signed a territorial sea boundary agreement on 25 May 1973 for the middle segment. Indonesia ratified the agreement on 3 December 1973 while Singapore ratified the agreement on 29 August 1974. The boundary line of the territorial seas of Indonesia and Singapore is a line, consisting of straight lines drawn between 6 points as mention in the agreement.

The territorial sea boundary extends for a distance of 24.55 nm. The average distance between the turning points is 4.91 nm, the minimum is 1.35 nm, and the maximum is 9.85 nm. Indonesia claims a 12 nm territorial sea dating from 1957 while Singapore claims a 3 nm territorial sea dating from 1957. The Indonesia-Singapore territorial sea boundary utilizes both the equidistant principle (3 turning points) and negotiated positions (3 turning points). Five of the six turning points lie on the Indonesia side of an Indonesia-Singapore median line. Of particular Interest is the location of point 2 which is located inside the Indonesia's baseline system and is therefore in Indonesian internal waters. Islands were utilized as base points for the construction of the territorial sea boundary [www.dtic.mil]. Up to now, the western segment and the eastern segment have not yet been demarcated. The Singapore reclamation which is done nearby this two segment could react some conflicts.

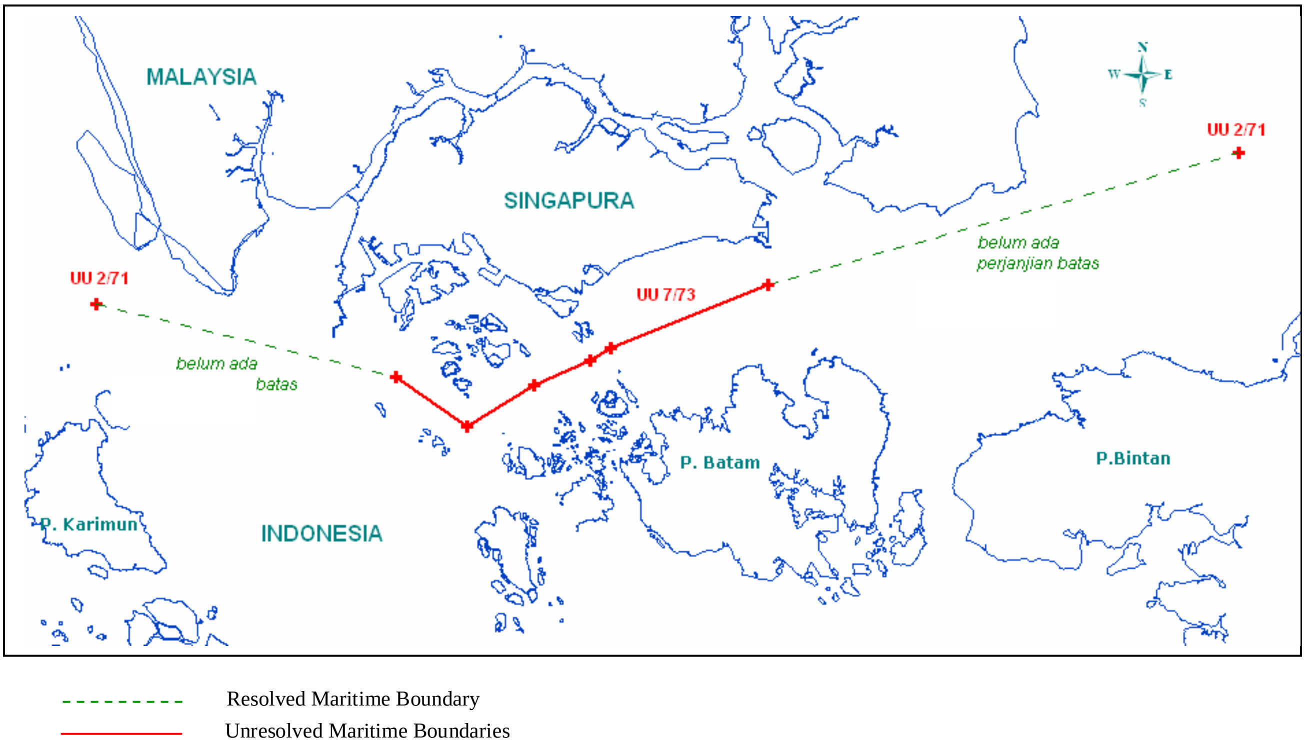

Figure 1: Study Area

3. METHODS

Since the baseline uses the low water line, this research assumed that boundary of land and water body shown in the image is the low water line. The image processing involved geometric correction to give coordinates to the image and some methods to determine the boundary between land and water body. The methods used are Image Enhancement using RGB Composite and Rationing, Image Classification using Supervised Classification and Density Slicing, BILKO and AGSO methods. From the visualization of the methods used, the boundary between land and water body is then digitized to visualize the baseline. Methodology of the research is shown in Figure 2.

3.1 Geometric Correction

Principally geometric correction makes the satellite image has a coordinate system which refers to the earth surface. This is carried out through image-to-map rectification, using Indonesia Archipelagic Baseline Charts in Natuna Sea, Malaka Gulf, and Singapore Gulf, scale of 1:200.000 as reference map. The ground control point (GCP) used is 18 points along the perimeter of the islands, while the mathematical model used is polynomial equations. WGS'84 is applied as a datum with coordinate system of NUTM48.

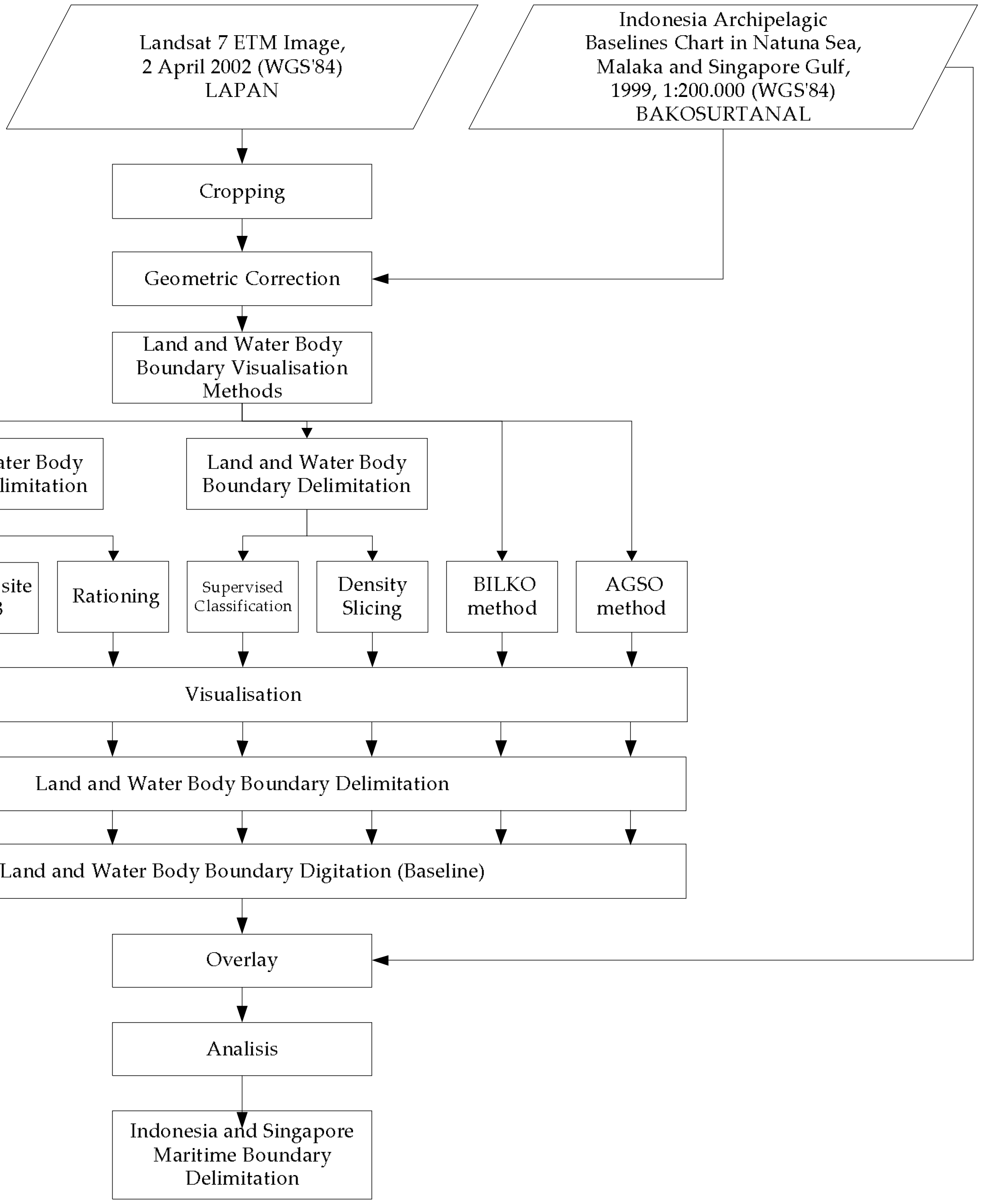

Figure 2: Research methodology

3.2 Image Enhancement

Image enhancement algorithms are applied to remotely sensed data to improve the appearance of an image for human visual analysis, or occasionally for subsequent machine analysis [Jensen, 1986]. In this research, RGB composite, Rationing, Spatial Filtering are applied to enhance satellite image. The best RGB composite is analyzed visually and statistically. Visually, Band 4 gives the best contrast between land and water body, because has low reflectance for the water and high reflectance for the land. From image statistics, the correlation between bands could be known. The less the correlation are from each band, the more information could be extracted. Based on the statistic computation, the best RGB composite is the composite of Band 1, 4 and 7 which gives the best visualization. The rationing method used the ratio of Band 2 and 5 which is useful for identifying all water bodies and provides some subtle wetland information [Jensen, 1986]. Spatial filtering is a mathematical technique for separating an image into its various spatial frequency components so that the analyst could extract useful information from the imagery. Algorithms to perform such enhancement are called filters. The filter used is Laplacian filter to get clear boundary between land and water body.

3.3 Image Classification

Image classification is one of the techniques in the domain of digital image interpretation based on the different spectral characteristics of different materials on the earth's surface [Janssen, 2001]. In a supervised classification, the identity and location of some of the land cover types are known a priori through a combination of field work, analysis of aerial photography, maps, and personal experience. The analyst attempts to locate specific sites is the remotely sensed data that represent homogeneous examples of these known land-cover types, commonly referred to as training sites. Multivariate statistical parameters are calculated for each training site. Every pixel both within and outside these training sites is then evaluated and assigned to the class of which it has the highest likelihood of being a member. The classification is divided into 3 classes: water, land and cloud. Reefs included in land class. Water is represented by blue color, land by yellow color, and cloud by white color. The algorithm used is minimum distance and standard deviation classification in Band 4 and 7.

Density slicing is the process of converting the continuous gray tone of an image into a series of density intervals, or slices, each corresponding to a specify digital range. From the statistical computation of the supervised classification, it is known that the water BV is less than 30 for Band 4, 5, and 7. So that the formula used is:

If INPUT 1<30 then INPUT1 else null

INPUT 1 of Red layer Red is Band 4, INPUT 1 of Green layer is Band 5, while INPUT 1 of Blue layer is Band 7. This formula will make the BV of non-water object as null.

3.4 BILKO and AGSO Methods

BILKO is software for image processing from Training and Education in Marine Science Programme (TREDMAR) – UNESCO. Based on Modul 7 Bilko Lesson 4, to determine the boundary of land and water body, it is needed to know the lowest BV of land and the highest BV of water from Band consisting of infrared wave. Infrared wave has low reflectance to water and high reflectance to the land. For Landsat Image it can be used Band 4 or Band 5 [Wardana, 2003]. The formula used is:

$$((BV_{Band4}/((N*2)+1)*(-1))+1$$

Where N is the highest BV of water from Band 4, which is 30.

AGSO (Australian Geological Surveys Organization) developed the algorithm to shallow water image mapping in Australia using image satellite. AGSO used a mathematical model to explain the correlation between electromagnetic wave signal, propagation medium, water particles, and the effect of water depth. Due to the spectral characteristics, water object has high reflectance in band between 0.3 –0,7 µm, which in Landsat is Band 1, 2, and 3. So these bands has ability to do the penetration to the surface of the sea and estimate the water depth. (Bierwirth, 1993). The formula used is:

If B5<D and B1>0 then (log (B1-m1)/K1) + (log (B2-m2)/K2) + (log (B3-m3)/K3) else null

Where:

D = the lowest BV of land in Band 5 =30

B5 = BV Band 5	B2 = BV Band 2
B1 = BV Band 1	B3 = BV Band 3
m1 = the lowest BV in Band 1 = 1	K_1 = attenuation coefisien in Band 1 = 0,1
m2 = the lowest BV in Band 2 = 1	K_2 = attenuation coefisien in Band 2 = 0,13
m3 = the lowest BV in Band 3 = 3	K3 = attenuation coefisien in Band 3 = 0,194

4. RESULT AND DISCUSSION

The visualization of each method is given in Figure 3. It can be seen that not all methods visualize the boundary between land and water body clearly, so that the digitations of the baseline is done by combining several methods to get the best result. The digitations result of the boundary between land and water body is shown in Figure 4. Each method has their own benefit and deficiency. The comparison of methods is given in Table 3.The demarcation of Indonesia and Singapore is done base on Home Affairs Department's book guidance to boundary demarcation and delimitation, also involving Singapore's area of reclamation. The design of the delimitation boundary map between Indonesia and Singapore is given in Figure 5.

To evaluate the geometric distortion, the method used is computing the root mean square error (RMS_{error}) for each of the GCPs. The RMS_{error} from the geometrics rectification is 0,297 pixels. This mean that the process is accepted, since the tolerance is 0, 5 pixels.

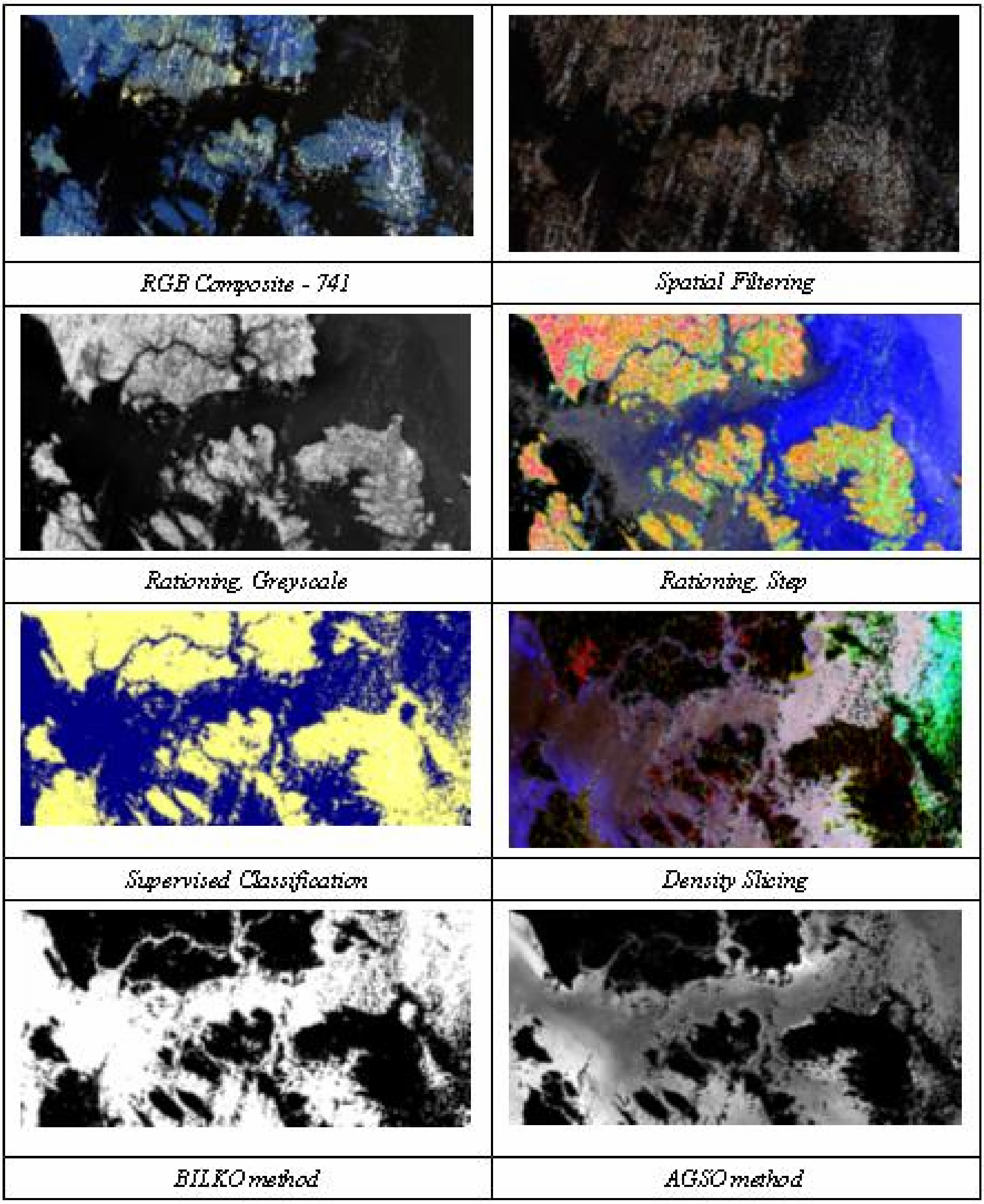

Figure 3: Visualization of the research result

Table 3: Methods comparison

Method	Benefit	Deficiency
RGB Composite	The visualization of land, water, cloud and fog are clear. The boundary between land and water body is clear enough.	Reefs are difficult to identify.
Spatial Filtering	For a small area with simple perimeter, the boundary between land and water body is clear.	Reefs are not identify. It cannot be used for large area.
Rationing Color Table: Greyscale	The boundary between land and water body is clear. Cloud and fog can be identify separately from land and water.	Reefs are not identify.
Rationing Color Table:Step	The boundary between land and water body is clear. Cloud and fog can be identify separately from land and water. In foggy area, reefs can be identify.	For area which is clear from fog, the reefs are not identify.
Supervised Classification	Reefs can be classified as land. The visualization of land, water, and cloud are clear. The boundary between land and water body is clear in the area without fog.	Fog is identify as land.
Density Slicing	The visualization of each object is clear enough. Land is black with blue color around, while cloud is black with grey color around. Reefs are green. Other colors indicated the water depth. The boundary between land and water body is clear enough.	The image visualization looks crowded.
BILKO Method	The boundary between land and water body is clear in area without cloud and fog.	Cloud and fog are identify as land.
AGSO Method	Land and water depth is clear enough. The boundary between land and water body is clear in area without cloud and fog.	Reefs and shallow water give the same color. Cloud and fog are identify as land.

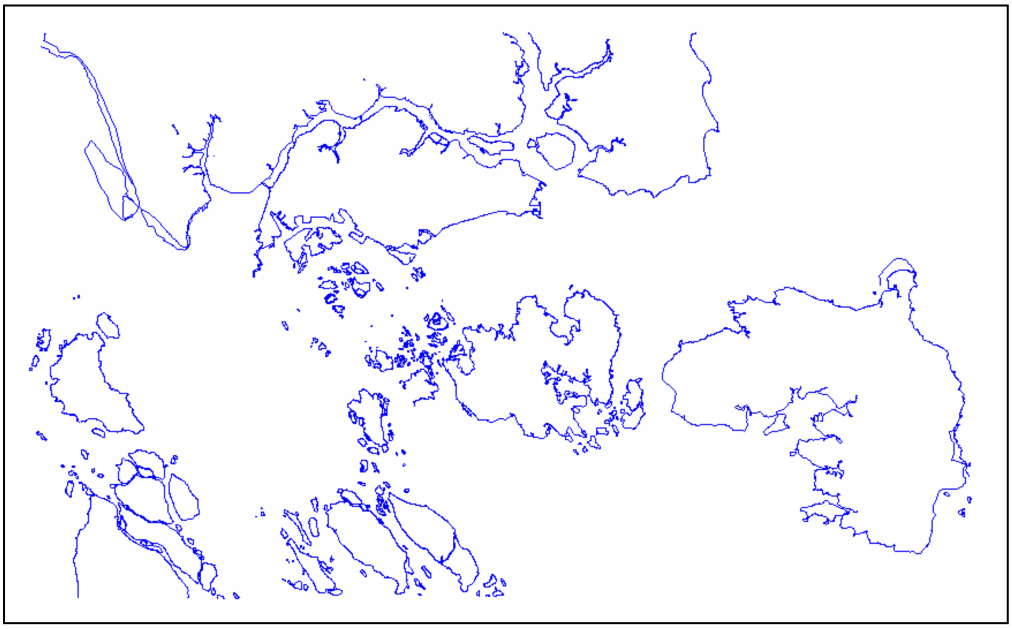

Figure 4: The digitations result of the boundary between land and water body

The crucial problem when using satellite image is the cloud and fog that disturbed the image. Other thing that is difficult enough to identify is the reefs, so that the reefs are mostly identify by comparing the image with the reference map. To get the best result, the digitation is done by combining several methods that give the best visualization of each area.

The boundary between land and water body is digitized manually on screen. When overlaying the digitations result with the reference map, the average of the shift is 71,482 meters. The equation used is

$$\Delta s = [(x_{map}-x_{image})^2 + (y_{map}-y_{image})^2]^{1/2}$$

Points used are the base points of Indonesia (10 points). This mean that the Landsat ETM image which is rectified using a reference map of scale 1:200.000 will produce image with scale 1:250.000 maximum. In Indonesia, the baseline and the territorial sea boundary chart uses chart of scale 1:200.000. So that the Landsat ETM image which is rectified using a reference map of scale 1:200.000 is not adequate to be used. While the EEZ and shelf continental shelf uses chart of scale 1:1.000.000 so that the Landsat ETM image which is rectified using a reference map of scale 1:200.000 could be used.

The image accuracy depends on the reference uses for the image rectification. In Indonesia, the reference maps/charts that could be used in boundary territory are:

- Indonesia Baseline Charts, scale 1:200.000
- Indonesia Coastal Environmental Chart, scale 1:50.000
- Navigational Chart
- Fair Charts, scale 1:5.000

For areas that have no charts, image rectification could use GCP's coordinate by GPS measurement.

Ref. Figure 5 at the end of the paper.

Maritime boundary reconstruction using Landsat ETM image has benefits that are:

- The visualization of the real condition is more up to date, so that it is more efficient to analyze the position of the base points and the baselines which are best used.
- For basepoints position which is difficult to be done the bathymetric measurement, the Landsat ETM image could be used.
- The reconstruction could be done in short time, so that it could be an effective technology to finish the charts to be given at the secretary general of United Nation at 2009.

5. CONCLUSION

- Landsat ETM Satellite Image is potential to be used to determine maritime boundary. Using a reference map of scale 1:200.000 for the geometric correction, the Landsat ETM Satellite Image could be used to predict the location of basepoints, and as acquisition data for EEZ and shelf continental charts. Using better reference for the geometric correction, the Landsat ETM Satellite Image could also be used as acquisition data for basepoints and sea territorial charts.
- The effective methods to be used to determine the baseline is the combination between density slicing, rationing, supervised classification, and RGB composite, that could give a clear visualization of the land and water body boundary.
- The geometric correction process should use reference map with suitable scale to give the best rectified image.

6. RECOMMENDATION

- Tide data and slope information should better used to get true position of the low water.
- Image rectification is an important process to get the accurate area, direction and distance measurement, so that it is important to take the reference maps/charts of scale minimum 1:100.000 to fulfill the requirement of Indonesia's baseline and territorial sea boundary chart of scale 1:200.000. For areas that have no charts, image rectification could use GCP's coordinate by GPS measurement.

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BIOGRAPHICAL NOTES

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Ketut Wikantika, Dr. Ir. M.Eng, received the Ph.D degree in 2001 from Chiba University, Japan, in remote sensing. Since 1992, he has been lecturer at the Department of Geodetic Engineering, Institute of Technology Bandung, and became an Associate Professor in 2004. His research interest is in environmental remote sensing from local to regional scales.

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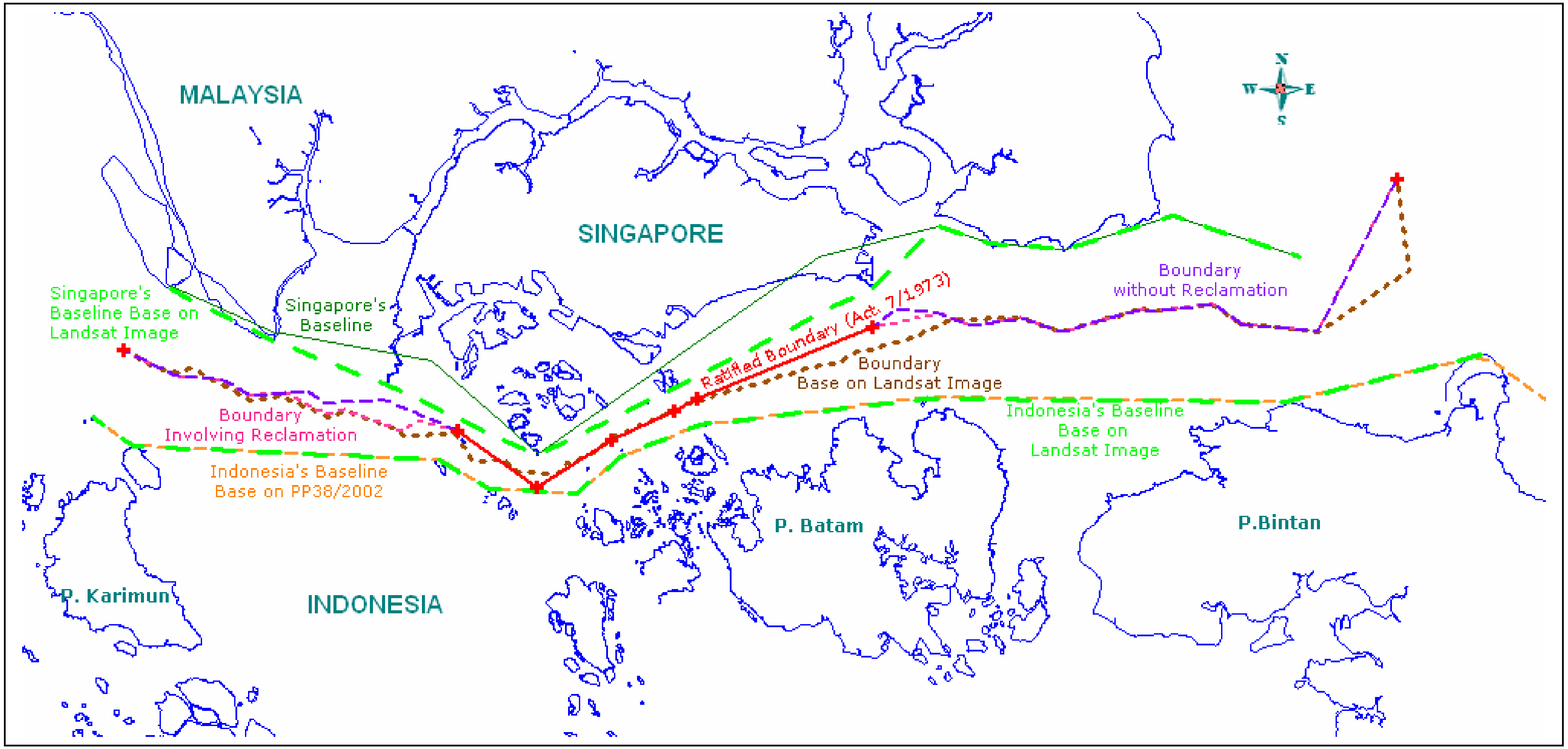

Figure 5: The design of the delimitation boundary map between Indonesia and Singapore