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The accuracy of the outer boundary delineation of coral reef area derived from the analyses of various vegetation indices of satellite landsat thematic mapper

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Abstract. *Sulistyo B. 2017. The accuracy of the outer boundary delineation of coral reef area derived from the analysis of various vegetation indices of satellite Landsat thematic mapper. Biodiversitas 18: 351-358.* This research aimed at determining the accuracy of the outer boundary delineation of coral reef area derived from the analysis of various vegetation indices of satellite Landsat Thematic Mapper in Enggano Island, the District of North Bengkulu, Bengkulu Province. The vegetation indices of Landsat Thematic Mapper analyzed were the Ratio Vegetation Index, the Normalized Difference Vegetation Index, the Soil Adjusted Vegetation Index, the Transformed Soil Adjusted Vegetation Index, the Modified Soil Adjusted Vegetation Index and the Transformed Vegetation Index. The result of every analysis of vegetation index (index map) was then used as a base for on-screen digitization of the points assumed to be the outer boundary of coral reefs in order to get digital data. Digitization of shoreline was also done to create an inner boundary of coral reefs. When it is combined with its outer boundary then the calculation of the area is possible. The accuracy of the result was validated by overlaying it onto Map of Coral Reefs derived from a topographic map of Joint Operation Group. To justify whether the accuracy is **good** (or **accepted**) or **not good** (or **not accepted**), a threshold value proposed by Justice and Townshend was chosen, those are **Poor** (when the accuracy is < 70%), **Moderate** (when the accuracy is between 70% and 85%), and **Good** (when the accuracy is ≥ 85%). The results of the research showed that the accuracy of RVI and NDVI values were **Poor**, those are 67.11% and 66.42%, respectively, so it could not be used for further analysis. The other results were **Moderate**, those are 73.33% for SAVI, 74.22% for TSAVI, 77.32 % for MSAVI and 77.33% for TVI, and may be used as a quick alternative when the map is absent.

Keywords: coral reefs, Landsat, outer boundary delineation, vegetation index
Abbreviations: JOG: Joint Operation Group, MSAVI: Modified Soil Adjusted Vegetation Index, NDVI: Normalized Difference Vegetation Index, RVI: Ratio Vegetation Index, SAVI: Soil Adjusted Vegetation Index, TSAVI: Transformed Soil Adjusted Vegetation Index

INTRODUCTION

The coral reef area in Indonesia is 50,875 km^2 or 18% of the world's coral reefs. However, in 2012 the area of coral reef area decreased to 39,500 km^2 (Burke et al. 2012). Coral reef ecosystem is a unique ecosystem found in tropical areas (Samuel et al. 2015). Coral reef ecosystems are fertile, biologically diverse and highly productive. Coral reefs also serve as breeding sites, and shelter for organisms that live in them. Various organisms living in coral reefs are biological sources that can be exploited for the benefit of humans, such as raw materials for pharmaceuticals and food. Furthermore, coral reefs contribute positively to marine fisheries and tourism (Suciati and Arthana 2008). Bertels et al. (2008) mention that coral ecosystems also offer an invaluable economic resource for the people living along the coast. However, these ecosystems are extremely sensitive to changes in the environment. Coral reef growth is affected by sunlight, temperature, salinity, water transparency, water movement, and the substrate, while the limiting factors include the water depth (coral reefs cannot thrive in waters deeper than 50-70 meters) and tides (coral reefs grow at a rate of the lowest tides). There are 3 types of reefs, namely fringing reefs/shore reefs, barrier reefs, and atoll.

Several years ago, most of the provinces in Indonesia, including Bengkulu Province, conducted an inventory of coastal and marine areas through a project-based activity called Marine and Coastal Resource Management. This activity is an early stage of coastal and marine area planning (Sulistyo 2007, 2012).

Every planning activity requires the availability of complete, detailed and up-to-date data. Such data are generally obtained by resource inventories. One of the necessary documents required for the integrated planning of coastal and marine areas is the Coral Reef Map. By knowing the boundary and distribution of coral reefs, the determination of the planning and development of coastal and marine areas can be conducted better.

Making up-to-date coral reef maps using conventional technology is not easy because it will take time, effort and high cost. Remote sensing is a technology which can provide up-to-date maps of large areas quicker, easier and cheaper (Mustafa et al. 2009; Warnasuriya et al. 2014). To know the information of objects that have been recorded by the sensors, one needs to interpret, i.e. to connect data recorded with real objects on the surface of the earth and assess their importance (Liang et al. 2012). Interpretation of digital data is an important process to obtain information from satellite data.

There are several interpretation techniques that can be used to obtain the delineation and the distribution of coral reefs, namely multispectral classification with maximum likelihood as done by Sulistyo (2007), while Pahlevan et al. (2006) and Benfield et al. (2007) used the algorithm of SWIM (Shallow Water Image Mapping). Another method is the object-oriented classification, which consists of two steps, i.e., segmentation and classification. Segmentation creates image-objects and is used to build blocks for further classifications based on fuzzy logic. Another method that has been used is ISODATA (Iterative Self-Organizing Data Analysis), which uses a combination of Euclidian squared distance and the reclassification of the centroid. A study conducted by Sulistyo (2007) revealed the Overall Accuracy of 80.47%, indicating that the accuracy obtained can be considered **good** (according to Daels and Antrop, 1981). However, the interpretation techniques to delineate the outer boundary of coral reefs based on the analysis of vegetation indices have never been implemented.

This study aimed to determine the accuracy of the outer boundary delineation of coral reefs area derived from the analyses of various vegetation indices of satellite Landsat Thematic Mapper in Enggano Island, the District of North Bengkulu, Bengkulu Province.

MATERIALS AND METHODS

Study site

The study was conducted from May to July 2016 in Enggano Island in the District of North Bengkulu, Bengkulu Province, Indonesia. Geographically, Enggano Island is located between 102.13^o and 102.44^o East longitude and between 5.27^o and 5.52^o South latitude. Enggano Island is 40,060 hectares, consisting of 6 villages with a population of about 2,864. Enggano Island is about 96 miles from the mainland of Bengkulu and can be reached using the ferry or, temporarily, a small airplane. The sea depth data published by the Department of Hydro Oceanography of the Navy shows that the coral reefs area is at a depth of less than 10 meters below sea level. Moreover, the water clarity is almost 100% in which one can see the bottom of the sea with the naked eye, except when the rains fall. Those conditions make it possible for the detection of the existence of coral reefs using Landsat Thematic Mapper. Coral reefs area lies between the coastline and outer edge of the reef crest. So, its outer limit is the outer edge of the reef crest. Coral reefs in Enggano Island consists of about 80% of DCA (Dead Coral Algae), while its lagoon is covered by seagrass and its subsequent is covered by algae.

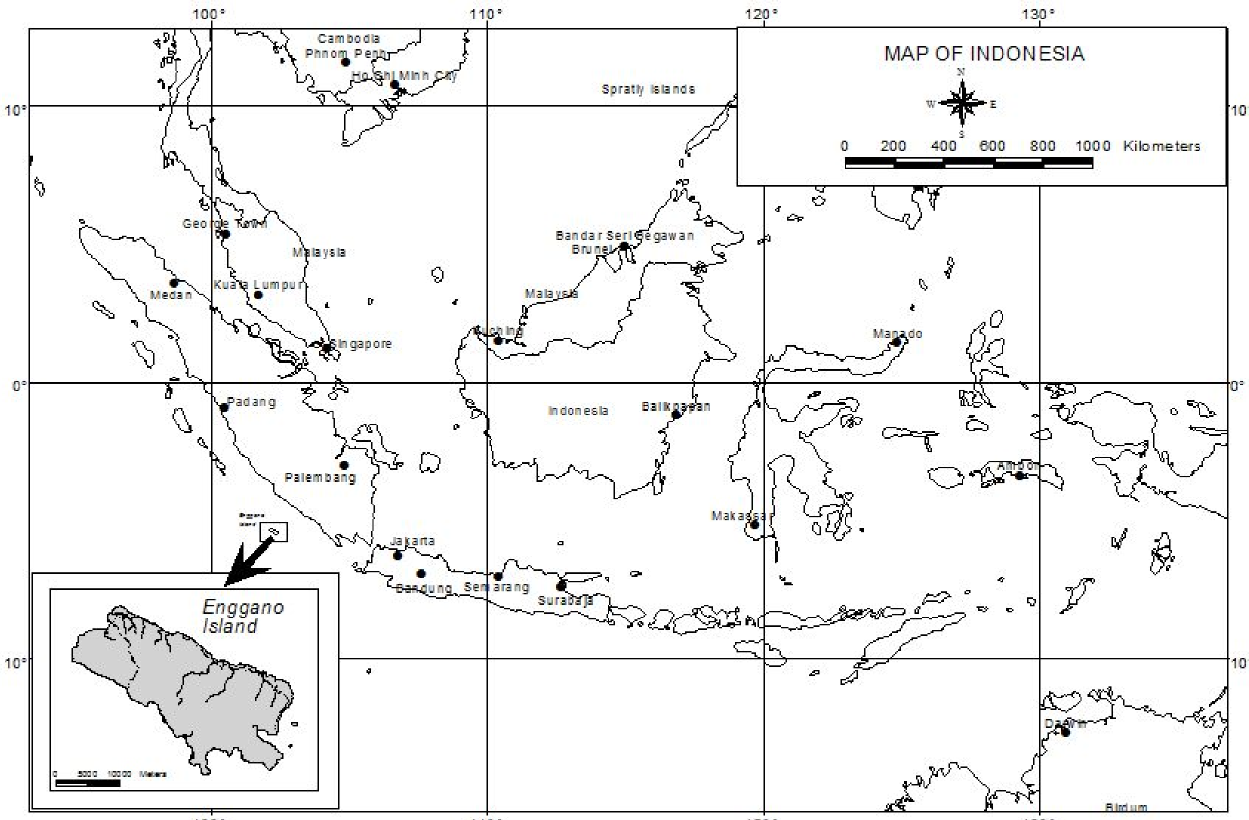

Figure 1. Location of the research in Enggano Island in the District of North Bengkulu, Bengkulu Province, Indonesia

Vegetation index analysis as a basis for delineation of coral reef outer boundary

In the analysis of digital of remote sensing data, there is an analysis called *vegetation index* (Danoedoro 2012). Vegetation index is a mathematical combination of satellite bands, which have been found to be a sensitive indicator of the presence and condition of green vegetation. It is based on the reflectance properties of vegetation in comparison with water on one hand and bare soil on the other hand. Vegetated areas have high reflectance in the near infrared and low reflectance in the visible red (Liang et al. 2012). One of the analyses of vegetation index is called the NDVI, calculated from the visible and near-infrared light reflected by vegetation. The healthy vegetation absorbs most of the visible light that hits it and reflects a large portion of the near-infrared light. Unhealthy or sparse vegetation reflects more visible light and less near-infrared light. Calculations of NDVI for a given pixel always result in a number that ranges from minus one (−1) to plus one (+1). However, no green leaves give a value close to zero. A zero means that there is no vegetation and close to +1 (0.8–0.9) indicates the highest possible density of green leaves, while negative values (< 0) indicates waterbody. NDVI is defined as (Silleos et al. 2006):

$$NDVI = \frac{(NIR - R)}{(NIR + R)} \quad (1)$$

where NIR and R indicate channel or band of Landsat Thematic Mapper near infrared and visible red respectively.

NDVI was originally developed by Rouse, Haas, Deering, Schell, and Harlan in 1974 (Silleos et al. 2006). Then, the concept of NDVI was modified by other scientists to take into account other factors. In 1975, Deering made modifications of NDVI into TVI by adding a constant of 0.5 at all values and then calculating the square root of the result. The addition of a constant 0.5 is aimed to avoid the negative value of NDVI, whereas the square root is intended to correct the NDVI value which is closer to the Poisson distribution than to Normal distribution. In 1988, Huete modified NDVI to be SAVI to minimize the effect of soil background on the vegetation signal by incorporating a constant soil adjustment factor L into the denominator of the NDVI equation. Subsequently, in 1991, Baret and Guyot modified SAVI into TSAVI by adding an additional correction factor of 0.08 to minimize the effect of brightness coming from a background of soil. Likewise, in 1994, Qi modified SAVI into MSAVI to minimize the effect of brightness coming from a background of soil in different vegetation cover (Silleos et al. 2006).

Some other vegetation index formulae are (Silleos et al. 2006):

$$RVI = \frac{(NIR)}{(R)} \quad (2)$$

$$SAVI = \frac{(NIR - R)*(1 + 0.5)}{(NIR + R + 0.5)} \quad (3)$$

$$TSAVI = \frac{\gamma\ (NIR - \gamma R - b)}{(\gamma\ NIR + R + \gamma b + X\ (1+ \gamma^2))} \quad (4)$$

$$MSAVI = NIR + c - \sqrt{\ ((NIR + c)^2 - 2\ (NIR - R))} \quad (5)$$

$$TVI = \sqrt{((NIR - R)/(NIR +))} + 0.5 \quad (6)$$

where **X** is the noise soil, i.e. 0.08, **γ** is the slope of soil line, i.e. 1.05, **b** is the coefficient value, i.e. 0.044, and **c** is the coefficient value to reduce the variation of soil calibration, i.e. 0.5.

Newly image as the result of the analysis of vegetation index also called as index map can then be used as a basis for digitization or delineation of coral reef outer boundary.

Procedures

The main data used in the study were the Map of JOG covering Enggano Island at a scale of 1: 100,000 (which was firstly published in 1942) and Landsat Thematic Mapper satellite imagery covering Enggano Island (path/row of 125/064) recorded in 2000. The analyses were performed using GIS Program called ILWIS (Integrated Land and Water Information System) version 3.4 and ArcView version 3.3. The stages of research were: (i) preparation, (ii) analyses of vegetation indices, (iii) Digitization (delineation), (iv) overlay analysis, and (v) the writing and map-making. The flow diagram of the study is presented in Figure 2.

Relevant literature, maps, satellite data, and equipment were prepared during the preparation phase. Prior to analyses of vegetation indices, radiometric correction (applying a simple radiometric correction based on subtraction of minimum values of the histogram) and geometric correction of the Landsat Thematic Mapper were done. The next step was digitization or delineation of the outer boundary of coral reefs. Digitization is the conversion of analog data into digital data. Digitization was done using the on-screen digitizing technique, that is performing digitization (delineation) on the imagery of the results of vegetation indices analyses, also called as index map, which is shown on the monitor. Digitization of shoreline was also done to create an inner boundary of coral reefs area such that when it is combined with its outer boundary then the calculation of the area is possible. Digitization was also carried out for the coral reefs shown on the map of JOG. At the overlay analysis phase, the result of digitization of coral reef-derived from index map (used as a ***Slave***) was overlaid on a coral reef-derived from map of JOG (used as ***Master***), in order to get the overall accuracy, errors of omission and errors of commission are come up (Strahler et al., 2006), as illustrated in Figure 3. Overall Accuracy is the correctly analyzed coral reef area, indicating that coral reefs exist not only in the Reference Map but also in the Results of Digitizing. Commission of Error is the area where the coral reefs are found only in the Reference Map but not in the Results of Digitizing, while Commission of Error is the area where coral reefs are not found in the Reference Map but they are found in the Results of Digitizing. To justify whether the accuracy is

good (or **accepted**) or **not good** (or **not accepted**) a threshold value proposed by Justice and Townshend (1981) is chosen. Justice and Townshend (1981) categorized threshold value into 3, those are **Poor** (when the accuracy is < 70%), **Moderate** (when the accuracy is between 70% and 85%), and **Good** (when the accuracy is ≥ 85%).

RESULTS AND DISCUSSION

The color composite of Landsat Thematic Mapper satellite imagery covering Enggano Island is presented in Figure 4. In general, the object of the coral reef appears in dark blue, the sea water is presented in black, clouds in white, while the vegetation is green. The reflectance range of NIR band in the reef area is between 11 and 137, while the Red band is between 30 and 220.

Coral reef map delineated from Map of JOG is presented in Figure 5, while coral reef maps delineated from the result of analyses of vegetation indices is presented in Figure 6. Their area is presented in Table 1.

The results of the interpretation of Landsat Thematic Mapper satellite imagery which was recorded in 2000 showed that the area of coral reefs in Enggano Island was 5,676.35 hectares (in average). Reefs grow around Enggano Island with thickness, i.e.the distance from the shoreline towards the sea, ranging from 200 meters (in the North) to 1,300 meters (in the East, South, and West). On the contrary, in the South coast of Enggano Island, where the presence of mangrove are rare (because the beach directly faces the waves from the Indian Ocean), the coral reefs are thicker. This shows that the waves are not extremely strong, so that coral reefs still grow.

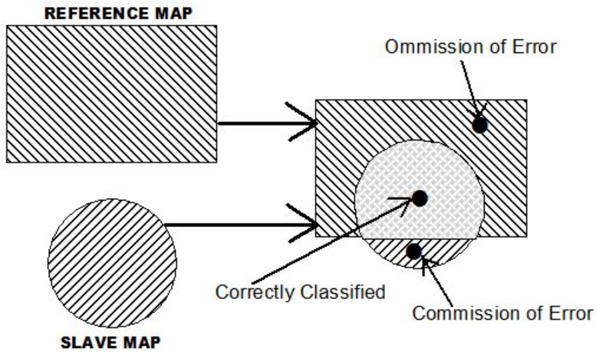

Figure 3. Illustration of the accuracy evaluation using overlay analysis

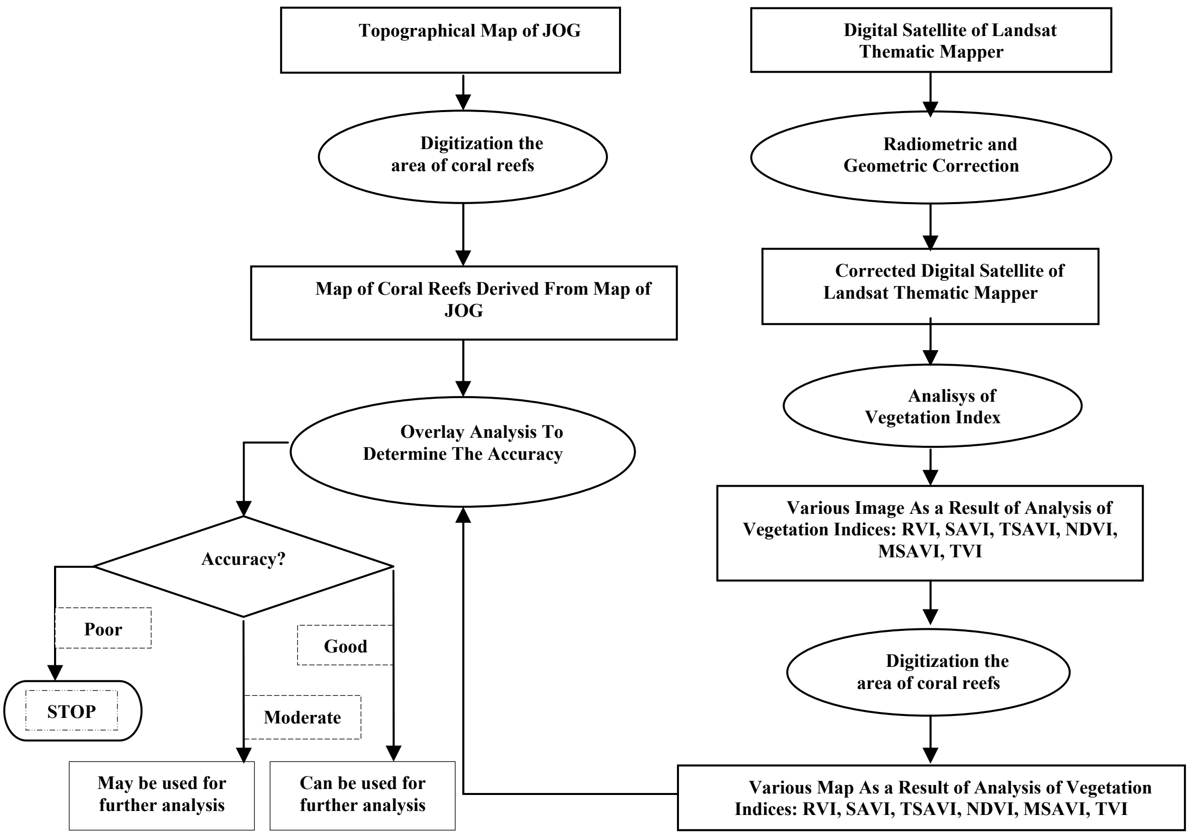

Figure 2. Flow diagram of the study

Figure 4. Color composite image of Landsat Thematic Mapper covering Enggano prior to analyses

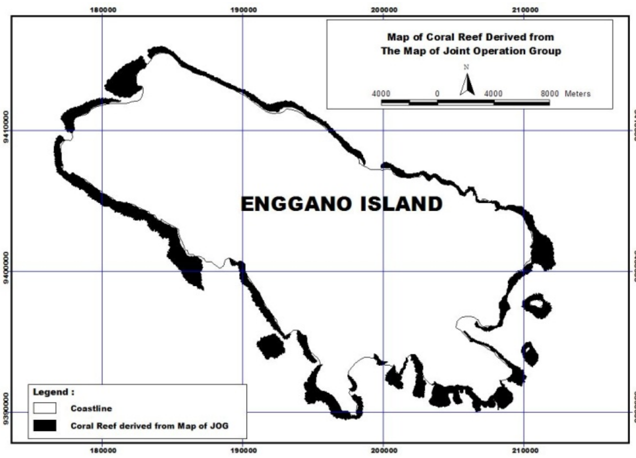

Figure 5. Map of coral reefs derived from Map of JOG

Table 1. Total area of coral reefs as a result of digitization

Data sources	Area (hectares)
Map of JOG (Reference)	6,116.18
Analysis of NDVI	4,964.93
Analysis of RVI	5,022.99
Analysis of SAVI	5,726.06
Analysis of TSAVI	5,750.51
Analysis of MSAVI	6,074.00
Analysis of TVI	6,079.79
Average	5,676.35

Table 2. The accuracy level of the results of the analysis of a several vegetation indices from Landsat Thematic Mapper

Vegetation index	Overall accuracy	Commission of error	Commission of error
NDVI	66.42	34.40	14.76
RVI	67.11	32.40	15.02
SAVI	73.33	26.78	20.29
TSAVI	74.22	25.72	19.80
MSAVI	77.32	22.62	21.99
TVI	77.33	22.61	22.07

In the planning of marine and coastal zone management, including coral reef conservation, it is important to have accurate data on both the area and distribution of coral reefs to avoid any over-estimate or errors. The accuracy values of the analyses of several vegetation indices are presented in Table 2.

The results showed that the Overall Accuracy values were between 66.42% and 77.33%, meaning that the Overall Accuracy valued of the digitization of Landsat image analysis results obtained from the analyses of vegetation indices were classified as **Poor** for NDVI and RVI (66.42% and 67.11% respectively), so that the information obtained could not be used for further purposes. Other results were classified as **Moderate** for SAVI, TSAVI, MSAVI and TVI (73.33%, 74.22%, 77.32% and 77.33% respectively). It reveals that the adjusted, transformed and modified vegetation indices are better than those original vegetation indices. These results were similar to the research done by Sulistyo et al. (2009) when applying various vegetation indices to map C factor to calculate erosion at the watershed. Vegetation indices considering soil background tend to result in a better map of C factor compared to those which are not considering soil background.

Actually, the Overall Accuracy achieved (between 66.42% and 77.33%) were not significantly different if it is compared to other similar research done by another researcher, and even higher. Awak et al. (2016) used satellite data of RapidEye to map benthic habitats in Owi Island, Biak, Papua ave and the overall accuracy was 73.42%. From the aspect of spatial resolution of satellite data that was used, then the analysis of various vegetation indices as a basis for digitization or delineation of coral reef outer boundary will give quite good result. Landsat Thematic Mapper only has a spatial resolution of 30 by 30 meters, whereas RapidEye has a spatial resolution of 6.5 by 6.5 meters. The Landsat Thematic Mapper has a lower spatial resolution than the spatial resolution of RapidEye. The spatial resolution is inversely proportional to the overall accuracy. Thus, the use of RapidEye satellite data should be able to produce the overall accuracy much higher than with the use of Landsat Thematic Mapper. However, it must be realized that the determination of the overall accuracy must consider many factors, some of which are i) desired end product; ii) desired accuracy; iii) extent of the study area; iv) available funding; v) logistics related to field work/ground truthing; and vi) available time (Ferreira et al. 2009).

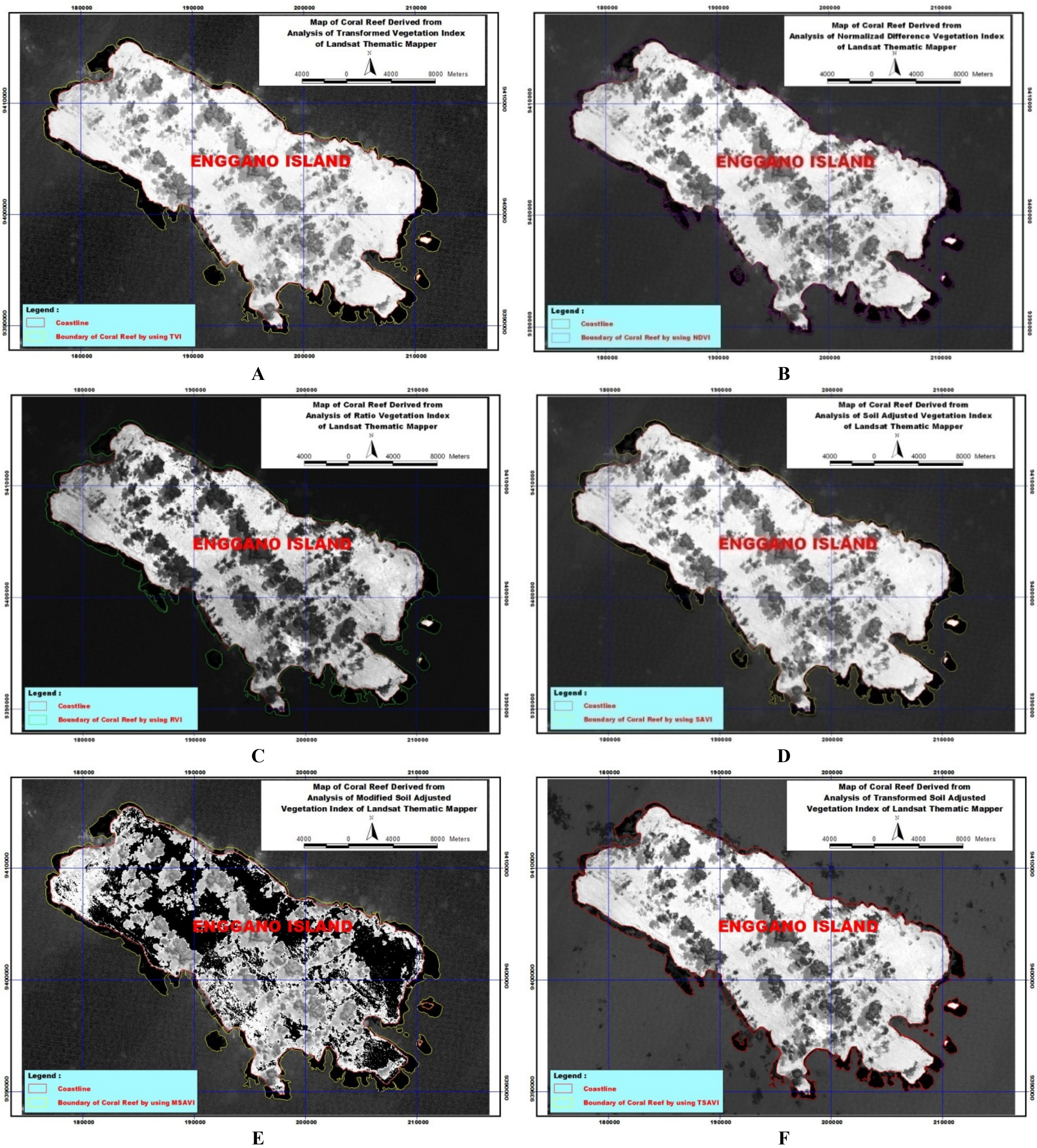

Figure 6. Maps of coral reefs as a result of the analyses of various vegetation indices from Landsat Thematic Mapper satellite

Nowadays, the use of remote sensing technology is something indispensable in various studies, including the mapping of coral reefs boundary. But, the current applicability and generalization of remote sensing research in coral reef habitat mapping remain problematic due to the intrinsic differences in each studied reef. The choice among several satellite data sources available (e.g. Landsat, SPOT, Ikonos, WorldView, QuickBird, RapidEye, CASI), all of which offer different degrees of accuracy, resolution and spectral characteristics, creates additional disparity. Finally, because of the use of various different habitat classification methods and mapping techniques, it is difficult to make comparisons between approaches, and this makes each mapping of coral reef habitats unique (i.e. Mumby and Edwards 2002; Purkis et al. 2002; Andrefoüet et al. 2003). Thus, it is not surprising if the purposes of the production of a map of major coastal habitats are as a background for further investigation, and for management, Mumby and Green (2000) assumed that a relatively low overall map accuracy (60%) is deemed appropriate. So, with the absence of a map of coral reefs in certain areas, analysis of vegetation indices using SAVI, TSAVI, MSAVI and TVI can be used as a quick alternative, although it is only limited to the information of the area, the inner and outer boundary of coral reefs.

The spectral characteristics of coral reefs usually depend very much on the absorption and scattering properties of their benthic substances. Coral reef communities are large mosaics of coral, algae, and sand. Both coral and algae contain chlorophyll and other photosynthetic pigments, while spectral curve values of sand are higher (Xu and Zhao 2014). Applying vegetation index analysis by using equation (1) to (6) produces a generalized (simplified) pixel value than the variation of its original pixel value in the NIR and Red band respectively. It means that vegetation index analysis can't be used to discern different features at the coral reefs area (such as living coral reefs, dead coral reefs, and coral reefs covered by algae). The more detail and comprehensive information related to coral reefs should still be collected by using other techniques which, usually, will take time, labor and cost. For example, to monitor the condition of coral reef ecosystems, it can be conducted by field survey, such as LIT (Lin Intercept Transect) or transect line, manta tow, belt transects and PIT (Point Intercept Transect) (English et al. 1994).

The values of Omission of Error and Commission of Error were logically smaller than the figures obtained because in fact there was a time difference between the reference map (which was firstly published in 1942) and the results of interpretation (using satellite data which was recorded in 2000. In reality, from 1942 to 2000, the coral reefs had the opportunity to change, but it hardly happens. Provincial Agency for Marine and Fishery (2004) reported that in Enggano Island there were visible cracks on some coral reefs area as a result of the earthquake that hit the Province of Bengkulu in the year 2000, with a magnitude of 7.9 on the Richter scale. Moreover, as it happens in other places, over the past three decades, coral reefs worldwide have experienced major changes in structure and function due to both anthropogenic and natural impacts (Hoegh-Guldberg et al. 2007; Mumby and Steneck 2008; Mahmud et al. 2015), and it seems that anthropogenic factor is considered to be the main factor to slow, and even to stop, the development of the reefs.

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