MAPPING CORAL REEF HABITAT WITH AND WITHOUT WATER COLUMN CORRECTION USING QUICKBIRD IMAGE

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Abstract

Remote sensing from space offers an effective approach to solve the limitation of field sampling, in particular to monitor the reefs in remote sites. Moreover, using the achieved remotely sensed data, it is even possible to monitor the historic status of the coral reef environment. The capabilities of satellite remote sensing techniques combined with the field data collection have been assessed for generating coral reef habitat mapping of the Derawan Island. A very high spatial resolution multi-spectral QuickBird image (October 2003) has been used. The capability of QuickBird image to generate a coral reef habitat map with the water column correction by applying the Lyzenga method, and also without the water column correction by the applying maximum likelihood method, have been assessed. The classification accuracy of the coral reef habitat map increased after the improvement of the water column effects. The classification of QuickBird image for coral reef habitat mapping increased up to 22% by applying a water column correction.

Keywords : Coral Reef, Quickbird, Water Column Correction

I. Introduction

Coral reefs are one of our earth's fundamental resources. Because of their rich habitat and large diversity of marine species and ecological complexity, coral reefs frequently compared to tropical rainforest. Coral reefs are an important asset for millions of people around the world, particularly for local communities who depend on these resources for their livelihood. The reef ecosystems provide pharmaceuticals, as a source of food, resulting income from tourism, and as a buffer for coastal cities and settlements from storm damage.

Coral reefs are distributed in the tropical and sub-tropical coastal waters, mostly in developing countries. The greatest diversity of coral reefs is in South-east Asia, ranging from the Philippines to the Great Barrier Reef in Australia. The coral reef in Indonesia is estimated to be roughly 85.700 km2, which is about 14% of the world's total area. They have a high biological diversity in the marine environment (Tomascik et al. 1997).

A monitoring program to detect changes of the coral reef environment is essential to promote sustainable management. The monitoring has to be repeated over time at the same location.

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An appropriate time scale is not only needed to study statistically changes in the main variables, but also to determine ecologically meaningful changes (Reese and Crosby 2000).

The common approach for monitoring of coral reef environments, i.e. field sampling, has its limitations. It requires large numbers of transect data to monitor the extent of the reef environment. It is costly and labour intensive and can be even more complicated if the location is in a remote area. Remote sensing offers an effective approach to solve the limitation of field sampling, in particular the monitoring of the reefs in remote sites. Moreover, using the achieved remotely sensed data; it is even possible to monitor the historic status of the coral reef environment.

The objective of the study was to assess the capabilities of the QuickBird image to generate a coral reef habitat map with water column correction, applying the Lyzenga method; and to compare it with a coral reef habitat map without the water column correction by applying maximum likelihood method.

II. Methodology

This study focuses on the coral reefs in the Derawan Island and Masimbung reef and Tubabinga reef in the southern part of Derawan Island. The Derawan islands region is a sub-district (Kecamatan) of the Berau district of the East Kalimantan Province, Indonesia. Geographically, it is situated between 118°09'53"-118°46' 28" East and the 02°25'45"-02°03'49" North. The islands of Derawan, Rabu-rabu, Panjang, Samama and Sangalaki are part of Bcrau barrier reef. The two up lifted atolls are Maratua, with an open lagoon and Kakaban, with a closed lagoon (Figure 1).

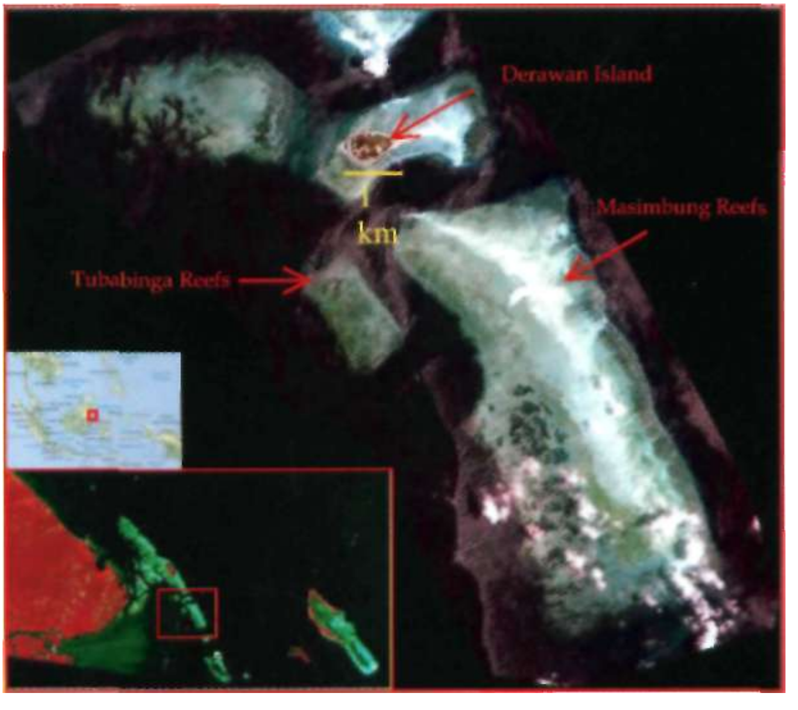


Figure 1. Study Area (Derawan Island - QuickBird 2003 RGB 321, Subset Derawan Islands region - Landsat ETM 2002 RGB 421)

The QuickBird image has been probided by ITC for the East Kalimantan Programme (F.KP) project. The image acquisition date (2 October 2003) corresponds approximately with the time of the field data collection. The image of the Berau region was acquired covering Dcrawan Island, Masimbung Reefs and Tubabinga Reefs. Table 1 describes the details of the available remote sensing data.

The fieldwork activities were carried out in October 2003 for one month, including 1 week for the secondary data collection and research equipment preparation, and 3 weeks in Dcrawan Islands (4 - 25 October 2003) for the in situ data collection. The field methods in Derawan Islands consisted of: ground control points collection, habitat ground truth points, *insitu* spectral data measurements, water depth measurements and habitat data collection along transects.

Image processing activities as describes in Figure 2 consist of: geometric correction, atmospheric correc-tion, water column correction, habitat classification and accuracy assessment. The water column correction for this study divides into 2 categories: with and without water column correction.

Table 1. Details of Quickbird (Krause 2003)

Sensor	: Quickbird
Path/Row	: User defined
Acquisition: Date Time (GMT)	 : 2 October 2003 : 10:23 A.M
Number of Bands	: Band 1 – 4 (spatial resolution 2.4 m) Panchromatic (spatial resolution 0.6 m)
Spectral range	:B1=450-520 B2= 520 - 600 B3=630-690 B4=760-900 B5= 1550- 1750 B6= 1040-1250 B7= 2080 - 2350 Pan= 450 - 900

2.1 Geometric Image Correction

Because the topographic map of the study area was not available for the geometric correction, ground control points were used as tie points. For resampling, the affinc transformation was used, because it is a simple one and commonly used for satellite images. It was difficult to find suitable ground control points. The Derawan Island is only a very small island, approximately 1 km long and 0,5 km wide. The high spatial resolution of the panchromatic QuickBird band (resolution 0,6 m) gave the possibility to use infrastructural elements as ground control points. In the field, the corner of some jetties surrounding the island, corners of a helicopter base and sand pit in the cast part of the island were collected as ground control points. The Root Means Square Error (RMSE) of the geometric image correction for the Quickbird panchromatic and multispectral bands are 4,667 (panchromatic) and 0,468 (multispectral) respectively.

2.2 Atmospheric Correction (Dark Pixel Subtraction)

The DN conversion to the satellite radiance is based on a technical note from the Digital Globe (Krause 2003). The QuickBird image has already radiometrically corrected pixel image ($q_{pixei,band}$)- This corrected only count specific to the QuickBird instrument, thus for example comparison to the in situ spectral reflectance, then the atmospheric correction have to be applied. For images generated after June 6, 2003 at 0:00 GMT, the equation is:

$$L = \frac{absCalFactorBand * q_{Pixel,Band}}{\Delta\lambda_{Band}} \quad (1)$$

where:

L	=	satellite radiance (W m^{-2} $ster^{-1}$ μm^{-1})
$q_{Pixel,Band}$	=	digital number values (counts)
absCalFactorBand	=	absolute radiometric

$\Delta\lambda_{Band}$ calibration factor (W m-2 sr-1 count-1), which is provided in header file, effective bandwidth of each band (um), which refers to the Digital Globe (Krause, 2003).

The conversion of satellite radiance to satellite reflectance referred to BILKO module seven (Edwards 1999) Reflectance is the ratio of the radiance to the irradiance, which depends on the wavelength. The following equation is used to calculate the apparent reflectance (p).

$$\rho = \frac{\pi . L . d^2}{ESUN . \cos(SZ)} \quad (2)$$

where:

ρ	=	satellite reflectance (range values of 0-1.)
π	=	3.14152
L	=	satellite radiance (mW cm^{-2} $ster^{-1}$ μm^{-1})
d^2	=	the square of the Earth-Sun distance in astronomical units
ESUN	=	Mean solar irradiance in mW cm^{-2} μm^{-1}.
SZ	=	sun zenith angle in radians.

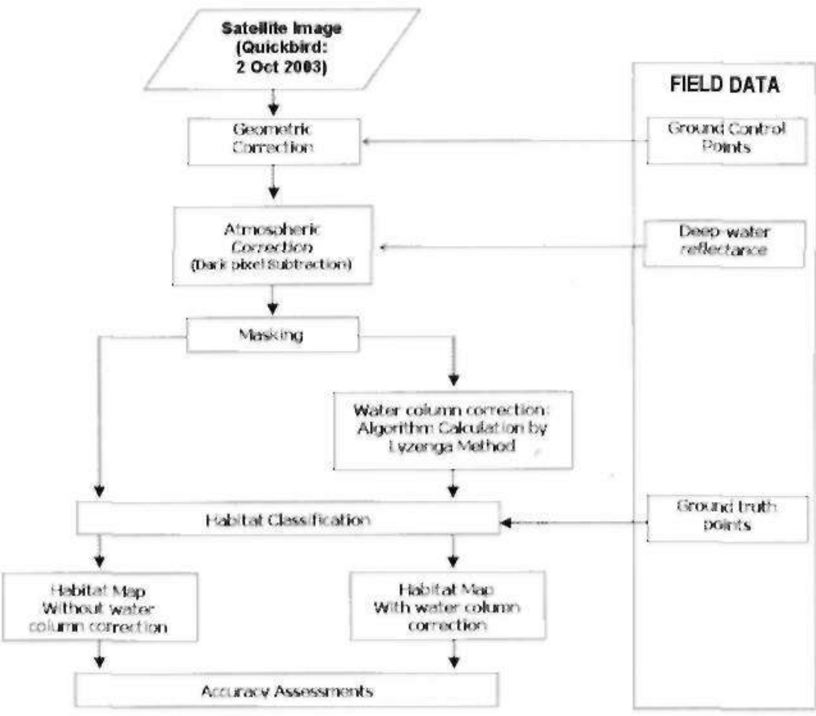


Figure 2. Flowchart of the research approach (Nurlidiasari, 2004)

The square of the Earth-Sun distance in astronomical units (d^2) is calculated using the following equation:

$$d^2 = (1 - 0.01674 \cos(0.9856 (JD-4)))^2 \quad (3)$$

JD is the Julian Day (day number of the year) of the image acquisition. The units of the cosine function of 0.9856 x (JD-4) will be in degrees. To convert the unit from degrees to radians is simply multiply by rc/180.

Insitu spectral reflectance data of deep water above the surface were used as a reference to correct the image for the atmospheric effects. Figure 3 shows the mean reflectance values of the deep-water reflectance (depth^ ~75 m) above the surface of the water, which were measured during the fieldwork. These values were used as a reference of in situ ground reflectance of dark pixels (deep water pixel) to convert satellite reflectance to ground reflectance retrieved from the image (Rg ~ R, where Rg is in situ ground reflectance and R is ground reflectance derived from image).

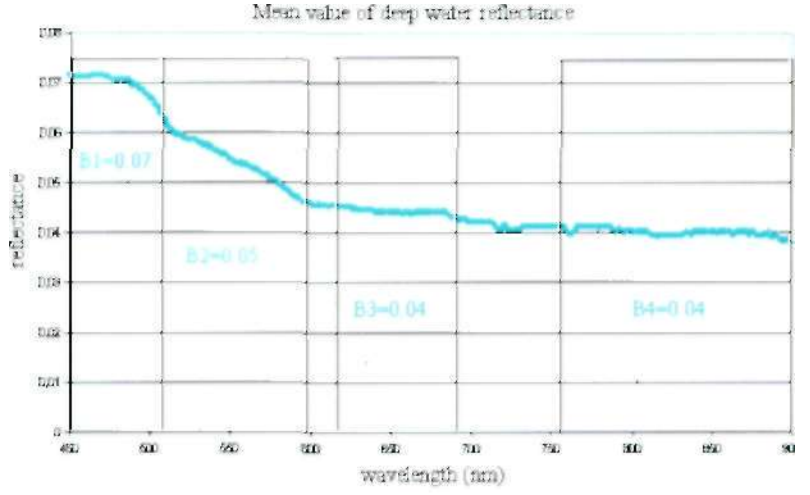


Figure 3. A graphic of ground reflectance mean values of deep water (Rg)

The mean of in situ ground reflectance (Rg) and deep water value of satellite reflectance (ρ_{dw}), were used to calculate the value of x. The x value is a certain values representing the influence of the atmosphere to reflectance recorded at the satellite. The following formula was used to calculate the x value:

$$X = \rho_{dw} - Rg \qquad (4)$$

The information of mean ground reflectance value (Rg), deep water value of satellite reflectance (ρ_{dw}) and the value representing the effects of the atmosphere (x) are listed in Table 2.

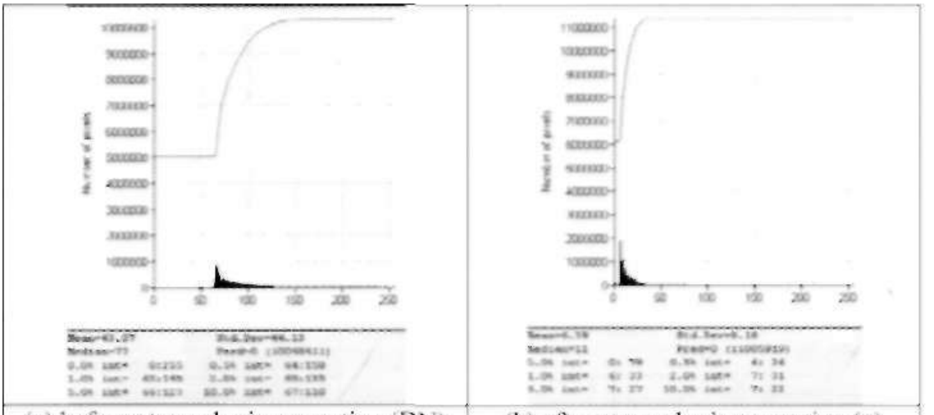
The formula to obtain ground reflectance retrieved from the image is:

$$R = \rho - x \qquad (5)$$

Table 2. Rg, ρ_{dw} and x values of each band

Band	Deep water value of reflectance at satellite (ρ_{dw})	Mean ground reflectance (Rg) of deep water	The value represents effects of atmosphere (x)
B1	0.23	0.07	0.16
B2	0.09	0.05	0.04
B3	0.07	0.04	0.03
B4	0.05	0.04	0.01

Where R ground reflectance values retrieved from the image band, p is the satellite reflectance, and x is the additional values due to the influence of the atmosphere, which was recorded at the satellite. Figure 4 shows that the mean value of band 1 of QuickBird before (a) and after (b) the application of atmospheric correction has decreased from 43.07 to 6.39.



(a) before atmospheric correction (DN) (b) after atmospheric correction (ρ)

Figure 4. Comparison of the histogram of band I QuickBird before (a) and after (b) the application of atmospheric correction

The mean of in situ ground spectral measurement of bright object (eg. sand beach) was compared to the mean of ground spectral of sand beach on the image. The ratio of the mean spectral reflectance of bright object between the field data and from the image shows correlation of 0.95, it is given by the following formula:

$$\frac{Rg}{R} = \frac{0.59}{0.62} = 0.95 \qquad (6)$$

where:

Rg = mean in situ measurement of ground spectral reflectance of sand beach.

R = mean ground spectral reflectance of sand beach on the image.

2.3 Water Column Correction

The concept of the water column correction is that bottom reflected radiance is a linear function of the bottom reflectance and an exponential function of the water depth. The intensity of light penetration is decreasing exponentially with increasing water depth; this process is known as attenuation. The approach proposes a method to compensate light attenuation due to the influence of depth using the information ratio attenuation of two bands (Lyzenga, 1981).

The homogenous substrate at various depths is selected from the image according to the following steps: Firstly, display a false colour composite of RGB 321 of the atmospheric corrected image. Secondly assess the homogenous substrate values (in this case sand) in the three bands and list them in an EXCELL spreadsheet. These values will be the inputs for the calculations in Equation 7.

The ratio attenuation is obtained using the following equations:

$$Ki/_{Kj} = a + \sqrt{(a2+1)} \qquad (7)$$

where:

$$a = \frac{\sigma ii - \sigma jj}{2_{\sigma ij}} \qquad (8)$$

and:

$$\sigma_{ij} = \overline{X_i X_j} - \overline{X_i}\ \overline{X_j} \qquad (9)$$

on is the variance of X, measurements, Oy is the variance of Xj measurements and Oy is the covariance of Xi and Xj. *Ki/Kj* is the ratio of the attenuation coefficient of band i and band j. The variance and covariance values are calculated using the values from Equation (7), (8) and (9).

The water attenuation has an exponential function with the increase of the depth. By applying a natural algorithm (In) to the atmospheric corrected image (in radiance units), this relationship will be linear. This step is written as:

$$X_i = \ln(L_i) \qquad (10)$$

where X_i = normalized image in b_i

L_i = atmospheric corrected image of b_i (radiance unit)

To generate a depth invariant index of bottom types within a pair of bands, the following formula is used:

$$\text{depth - invariant index}_{ij} = x_i - \left[\left(\frac{k_i}{k_j}\right) * (x_j)\right] \qquad (11)$$

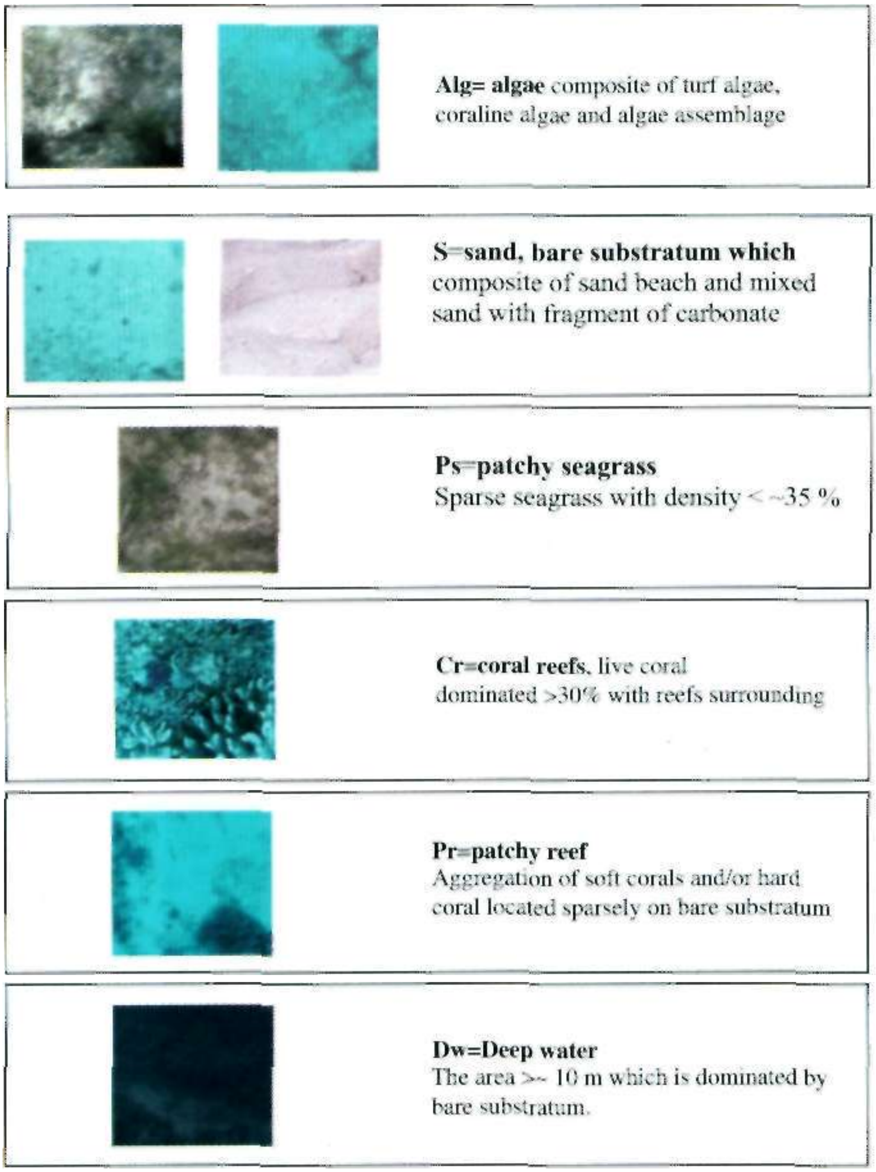


Figure 5. Description of habitat classes

2.3 Categorization Habitat Classes

The categorization of habitat classes in this study is more based on the ecological classification approach. The Ecological classification is not as straightforward as the geomorphological approach. The ecology of a habitat may be limited to the assemblage of plant and animal species and the substrate. Examples of the ecological classification classes are: coral, algal dominated, bare substratum dominated and seagrass dominated (Mumby, 1998). Figure 5 shows descriptions of the habitat classes for this study which was represented the habitats in the study area. For seagrass habitat, only patchy seagrass is determined since high density seagrass was not found.

2.4 Accuration Assessment

The **most** common accuracy assessment of classified remotely sensed data is the error matrix, known as the confusion matrix. This is done by comparing the classified image, as the result map, to the 'true world classes. The true world classes are preferable derived from field observations (e.g. ground truth sampling points). There are three types of accuracy that can be generated from error matrix: overall accuracy, producer accuracy and user accuracy. The overall accuracy represents the number of correctly classified pixels. The producer accuracy indicates the probability that a sampled point on the map is the particular class. The user accuracy indicates the probability that a certain reference class has also been labelled the class that is indicated (Janssen and Huurneman 2001).

III. Results and Discussions

One of the hypotheses of the study is that the water column correction technique can produce a more accurate coral reef habitat map from QuickBird **data of** October 2003. In remote sensing of shallow water habitat mapping, one has to deal with the influence of the atmosphere and the water column. The radiation must pass through two media, the atmosphere and water and pass it again on its way back before being recorded at the sensor. Therefore to identify bottom reflectance, the image should be corrected for both atmospheric and water column effects. In order to assess the effect of the water column correction for coral reef habitat mapping, a coral reef habitat classification without water column correction has to be made as a comparison.

3.1 Generating a coral reef habitat map without water column correction

the habitat classes have been defined, which include: algae composite, coral reef, patchy reef, patchy seagrass, sand and deep water. The input for this classification is a maplist of the atmospheric corrected QuickBird image of 2003, which can only cover the shallow water part of the study area. The maplist consist of bands 1, 2 and 3 of the QuickBird image. The training samples have been selected using half of the total number of habitat ground truth points. The selected training samples were evaluated using the feature space option.

After the evaluation of the training set, the maximum likelihood algorithm was used to generate the classified image. During the classification processes, the first result did not meet the expectation, and the classification was repeated by re-selection of the training samples. The result of the coral reef habitat map without water column correction is presented in Figure 6.

The next step was to assess its accuracy. For improvement of the accuracy assessment, half of the total numbers of habitat ground truth points were compared with the classified image. The result of the accuracy assessment is presented in Table 3.

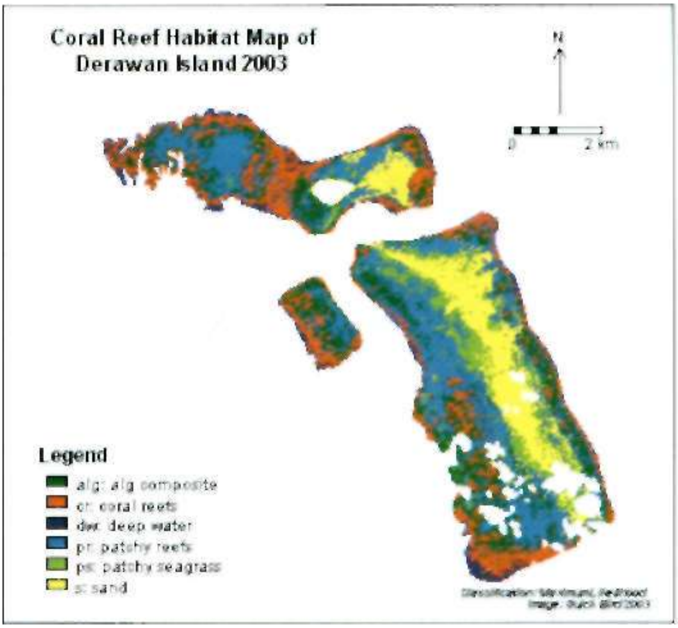


Figure 6. Coral reef habitat map of QuickBird image of October 2003, without water column correction

3.2 Generating a coral reef habitat map with water column correction

For generating a habitat map with water column correction, a water column corrected image is required. To compensate the water column effect, the "depth invariant index" method (also known as Lyzenga method) is used.

The next step was to assess the homogenous substrate values (in this case sand) in the three bands image using pixel information and on the scatter plot, most of the pixels values between band I and band 2 were falling on a strait line (Figure 7.(a)), however, this is less the case between band 2 and band 3 (Figure 7.(b)). This is caused by the larger light attenuation of band 3 in the water column. Based on this result, for the next step, only pair of band I and band 2 was used.

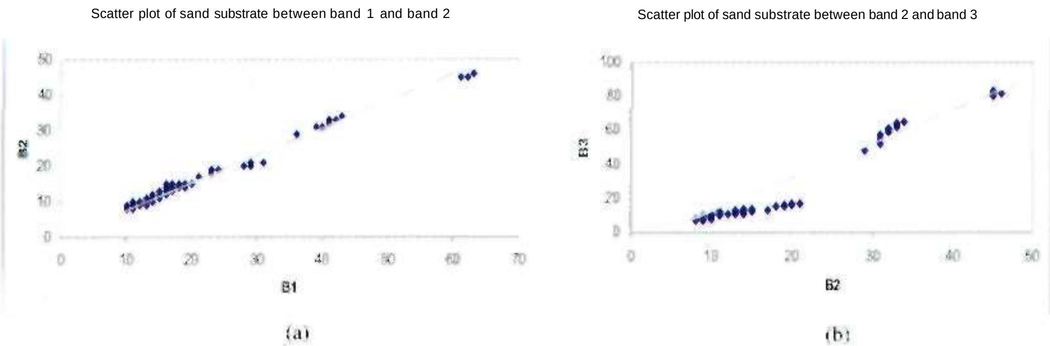


Figure 7. (a) Scatter plot of sand substrate at various depths between band I and band 2, and (b) between band 2 and band 3.

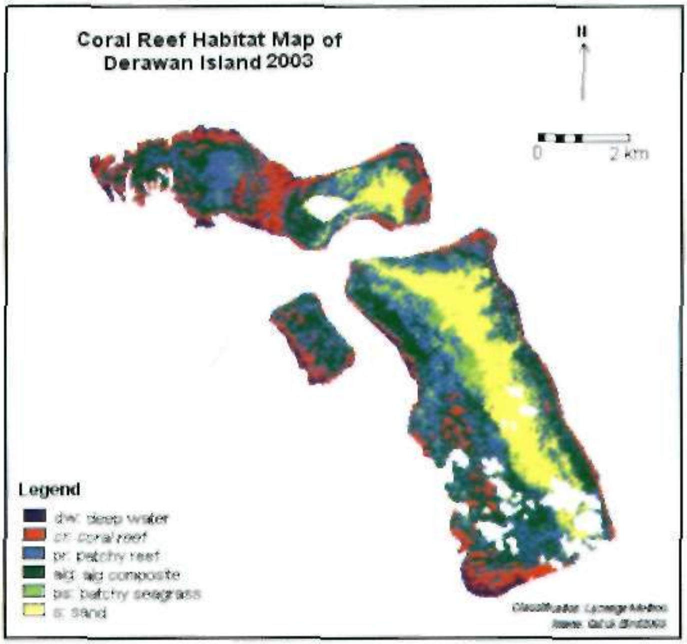


Figure 8. Coral reef habitat map of QuickBird image of October 2003, with water column correction

After the ratio attenuation coefficient (kj/kj) is obtained and the input bands have been linearised, a depth invariance index map was generated by applying Equation 11. With this way, an image has been obtained in which the water column effect has been compensated.

The input classification map is a depth invariant index of a pair of band 1 and 2. The training samples are selected, using half the number of the ground truth habitats points (the same points that were used in generating habitat map without water column correction.). After having selected the training samples, a parallelepiped classification decision rule is used to classify the image.

The parallelepiped classification approach was carried out by using the density slicing option. The values of the training sample pixels were used as the thresholds. The limits, were maximum and minimum values, means plus and minus of standard deviation values. After the threshold boundary of each class was determined, the image was classified. The output of the classified image was evaluated; if this was not acceptable, the classification processes was repeated by reselecting training samples or/and threshold boundaries. The output of the classified image, which is a coral reef habitat map with water column correction, is presented in figure 8.

3.3 Accuracy assessment

For the accuracy assessment, half of the total numbers of habitat ground truth points were compared with the classified image. The result of the accuracy assessment is presented in Table 3 for map without water column correction and Table 4 for map with water column correction.

Table 3 and Table 4 indicate that water column correction increased the accuracy of coral reef habitat mapping. The accuracy of patchy seagrass, patchy reef, sand and algae has increased after the water column correction. This was respectively 60%, 80%, 78% and 47% before water column correction and 80%, 93%, 100% and 89% after the correction.

Table 3. Error matrix of the classified image without water column correction

	(cr)	(dw)	(ps)	(pr)	(s)	(alg)	User Accuracy (%)
Coral reef (cr)	5	2	ll	0	0	0	71
Deep water (dw)	0	2	0	0	0	0	100
Patchy seagrass (ps)	0	0	3	2	0	0	60
Patchy reef (pr)	2	0	0	12	0	0	80
Sand (s)	0	0	2	0	7	0	78
Algae (alg)	2	0	0	8	0	9	47
Producer Accuracy (%)	56	50	60	55	100	90	

Total accuracy: 67 %

Table 4. Error matrix of the classified image with water column correction

	(cr)	(dw)	(ps)	(pr)	(s)	(alg)	User Accuracy (%)
Coral reef (cr)	5	2	0	0	0	0	71
Deep water (dw)	0	2	0	0	0	0	100
Patchy seagrass (ps)	0	0	4	1	0	0	80
Patchy reef (pr)	0	(1	1	14	0	0	93
Sand (s)	0	0	0	0	9	0	100
Algae (alg)	1	0	0	1	0	17	89
Producer Accuracy (%)	83	10(1	80	88	100	100	

Total accuracy: 89 %

IV. Conclusion

In this study, the remote sensing technique to compensate with the water column effect using the depth invariant method has been attempted to the QuickBird image. It is concluded that the depth invariant index can be applied to enhance the bottom type information and compensate the water column effect.

The results demonstrate that water column correction can increase the quality of the coral reef habitat map. The accuracy of patchy seagrass, patchy reef, sand and algae has increased after the water column correction. This was respectively 60%, 80%, 78% and 47% before water column correction and 80%, 93%, 100% and 89% after the correction. The increase in the accuracy of patchy seagrass, patchy reef, sand and algae shows that by applying depth invariant index method, the bottom type information has been enhanced.

However, the accuracy of coral reef and deep water are similar (71% and 100% respectively), before and after water column correction. This similarity may be because these bottom types are quite distinct compared to other habitats so there was no improvement in term of accuracy. Another reason may be due to insufficient validation points (total 7 and 2 points for coral reef and deep water respectively). The total accuracy of coral reef habitat map has increased before and after water column correction from 67 % to 89% respectively.

Acknowledgment

This research was part of the project of the East Kalimantan Programme for Coastal Zone Research Netherlands-Indonesia (EKP); a join research between the Netherlands and Indonesia institutions funded by The Netherlands Foundation for the Advancement of Tropical Research (WOTRO), Thanks to ITC staff (Drs. Michel Damen, Dr. Ir. Tjeerd Hobma, Drs. Boudewijn van Lecuwcn and Drs. Harald van der Werff) for their valuable comments. Dr. Bert Hoeksema, Prof. Dr. Rolf P.M. Bak, Ibu Yosephine and Pak Suharsono and Dr. Emre Turak, Drs. Sybrand van Beijma and Drs. Arjan Reesink, and Ana Fonseca for interesting discussions in the field.

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