SEA BOTTOM MAPPING FROM ALOS AVNIR-2 AND QUICKBIRD SATELLITE DATA

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PRESENTATION OUTLINE

1. Introduction
2. Study Area
3. Satellite Data
4. Methodology
5. Results
6. Analysis
7. Conclusion
INTRODUCTION

• Seaweed and seagrass are both marine plants that live in the seawater.

• Coral reefs are found in shallow tropical waters along the shores of island and continents. It is very sensitive to small environmental perturbations over a short period.
• Seaweed has been found to be influenced by pollution, where the brown and red seaweed tend to die and the green seaweed takes over.

• Seagrass has been known to die when exposed to high levels of pollution.
Remote sensing offers accurate and up-to-date techniques that can continuously monitor changes of sea bottom features at any scale of resolution.
• Sibu Island
<table>
<thead>
<tr>
<th>Area</th>
<th>Satellite data</th>
</tr>
</thead>
</table>
| Sibu Island | ALOS AVNIR-2  
                   | Quickbird               |
RAW ALOS AVNIR-2 IMAGE (29 JULY 2008)
SIBU ISLAND
RAW QUICKBIRD IMAGE (13 August 2007)
SIBU ISLAND
Sea Truth Data (18 August 2008)
### Sea Truth Equipment

- Sibu Island:

<table>
<thead>
<tr>
<th>Equipment Name</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handheld Garmin GPS</td>
<td>To obtain the ground coordinates of the ground control points, sea truth points and location of boundary points for different sea bottom features</td>
</tr>
<tr>
<td>Echo sounder</td>
<td>To identify the location and type of sea bottom that cannot be seen directly</td>
</tr>
<tr>
<td>Diving instruments</td>
<td>To dive in the location in the geographical area to verify whether particular sea bottom types exist</td>
</tr>
</tbody>
</table>
Methodology

• Pre-processing
  – Conversion of DN to radiance

• Sun glint removal (for Quickbird Imagery)

• Processing
  – *Method 1: Depth invariant index method*
  – *Method 2: Bottom reflectance index method*
DN to Radiance Conversion

DN-to-radiance conversion for ALOS data:

\[ L_\lambda = G_{\text{rescale}} \times Q_{\text{cal}} + B_{\text{rescale}} \]

Where,

- \( L_\lambda \) = spectral radiance at the sensors aperture in \( \text{W}/(\text{m}^2\cdot\text{sr}\cdot\mu\text{m}^{-1}) \)
- \( G_{\text{rescale}} = \frac{L_{\text{MAX}_\lambda} - L_{\text{MIN}_\lambda}}{Q_{\text{cal max}}} \)
- \( B_{\text{rescale}} = L_{\text{MIN}_\lambda} \)
- \( Q_{\text{cal}} \) = quantized calibrated pixel value in DNs
- \( L_{\text{MIN}_\lambda} \) = spectral radiance that is scaled to \( Q_{\text{cal min}} \) in \( \text{W}/(\text{m}^2\cdot\text{sr}\cdot\mu\text{m}^{-1}) \)
- \( L_{\text{MAX}_\lambda} \) = spectral radiance that is scaled to \( Q_{\text{cal max}} \) in \( \text{W}/(\text{m}^2\cdot\text{sr}\cdot\mu\text{m}^{-1}) \)
- \( Q_{\text{cal min}} \) = minimum quantized calibrated pixel value (DN) corresponding to \( L_{\text{MIN}_\lambda} \)
- \( Q_{\text{cal max}} \) = maximum quantized calibrated pixel value (DN) corresponding to \( L_{\text{MAX}_\lambda} \)

(Source: Bouvet et al 2006)
## DN to Radiance Conversion

### ALOS AVNIR-2

<table>
<thead>
<tr>
<th>Band</th>
<th>$G_{\text{rescale}}$</th>
<th>$B_{\text{rescale}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.941</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0.914</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0.804</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0.835</td>
<td>0</td>
</tr>
</tbody>
</table>

(Source: Bouvet et al 2006)
DN to Radiance

- DN-to-radiance conversion for Quickbird data:

\[ L_{\lambda \text{Pixel, Band}} = \text{absCalFactor Band} \times q_{\text{Pixel, Band}} \times \frac{\Delta \lambda}{\text{Band}} \]

where,

- \( L_{\lambda \text{Pixel, Band}} \) = Top-of-atmosphere band integrated radiance image pixels (Wm\(^{-2}\) sr\(^{-1}\))
- \( \text{absCalFactorBand} \) = Absolute radiometric calibration factor (Wm\(^{-2}\) sr\(^{-1}\)count\(^{-1}\))
- \( q_{\text{Pixel, Band}} \) = digital number values (counts)
- \( \Delta \lambda \text{Band} \) = Effective bandwidth for a given band (μm)

(Source: Krause, 2003)
• Quickbird absolute radiometric calibration factor (absCalFactorBand):

<table>
<thead>
<tr>
<th>Spectral band</th>
<th>absolute radiometric calibration factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>450-520 nm (Blue)</td>
<td>0.01604120</td>
</tr>
<tr>
<td>520-600 nm (Green)</td>
<td>0.01438470</td>
</tr>
<tr>
<td>630-690 nm (Red)</td>
<td>0.01267350</td>
</tr>
<tr>
<td>760-900 nm (NIR)</td>
<td>0.01542420</td>
</tr>
</tbody>
</table>
• Quickbird effective bandwidth ($\Delta \lambda$)

<table>
<thead>
<tr>
<th>Spectral Band</th>
<th>Effective Bandwidth ($\mu$m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pan</td>
<td>0.398</td>
</tr>
<tr>
<td>Blue</td>
<td>0.068</td>
</tr>
<tr>
<td>Green</td>
<td>0.099</td>
</tr>
<tr>
<td>Red</td>
<td>0.071</td>
</tr>
<tr>
<td>NIR</td>
<td>0.114</td>
</tr>
</tbody>
</table>
Sun glint removal (for Quickbird Imagery)

- Sun glint occur during clear skies and wave formation on high spatial resolution images (Hedley et al. 2005).

- Hochberg et al. (2003) proved that near-infrared (NIR) band was effective to remove sun glint.
Sun glint removal (for Quickbird Imagery)

- Sun glint removal equation is as follows:

\[ R_i' = R_i - b_i (R_{\text{NIR}} - \text{Min}_{\text{NIR}}) \]

where,
- \( R_i' \) = radiance in the deglinted image
- \( R_i \) = radiance value in band \( i \)
- \( b_i \) = regression slope
- \( R_{\text{NIR}} \) = radiance value in NIR band
- \( \text{Min}_{\text{NIR}} \) = minimum radiance value in NIR band

(Source: Hedley et al., 2005)
Sun glint removal (for **Quickbird** Imagery)

- Relationship between visible band and NIR band for glinted image
Method 1: Depth invariant index method

- The technique for extracting bottom-type information depends upon the fact that bottom-reflected radiance is approximately a linear function of the bottom reflectance and an exponential function of the water depth.
- The Depth Invariant Index is given by,

\[ Y_i = \frac{K_j \ln (L_i - L_{si}) - K_i \ln (L_j - L_{sj})}{\sqrt{(K_i^2 + K_j^2)}} \]

where,

- \( Y_i \) = depth invariant index
- \( K_i \) = attenuation coefficient for band \( i \)
- \( K_j \) = attenuation coefficient for band \( j \)
Depth Invariant Index
(Removal of atmospheric effects and external reflection from the water surface)

• To solve the depth invariant index equation, the measured radiance are transformed according to the following equation (Lyzenga, 1981),

\[ X_i = \ln (L_i - L_{si}) \]
\[ X_j = \ln (L_j - L_{sj}) \]

where,
\[ L_i = \text{measured radiance in band i} \]
\[ L_{si} = \text{deep-water radiance in band i} \]
\[ L_j = \text{measured radiance in band j} \]
\[ L_{sj} = \text{deep-water radiance in band j} \]
In this study, two visible bands were used which are:

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Band 1</th>
<th>Band 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALOS Data</td>
<td>0.42-0.50 μm</td>
<td>0.61-0.69 μm</td>
</tr>
<tr>
<td>Quickbird Data</td>
<td>0.45-0.52 μm</td>
<td>0.63-0.69 μm</td>
</tr>
</tbody>
</table>

This is because the bottom recognition processing is determined by a trade-off between depth of penetration and sensitivity to reflectance changes. The sensitivity to changes in bottom reflectance is largest for bands having the greatest difference in attenuation coefficients.

In this case, band 1 has maximum depth penetration while band 3 has a good compromise between sensitivity to reflectance changes and penetration depth (Lyzenga et al. 1981).
(1) Depth Invariant Index

• If $X_i$ is plotted versus $X_j$ and water depth varied, the data points will fall along a straight line whose slope is $K_i / K_j$ where $K_i$ and $K_j$ are attenuation coefficients of water in band $i$ and band $j$ respectively.

• If the bottom reflectance is changed, the data points will fall along a parallel line which is displaced from the first.

• By measuring the amount of displacement, a change in bottom reflectance can be detected even if the water depth is unknown.
In order to improve mapping accuracy, Sagawa (et al. 2010) proposed an alternative radiometric correction. This index is linearly related to bottom reflectance.
The new reflectance index is expressed by the following equation,

\[
BRI = \frac{(L_i - L_{si})}{(\exp(-K_i g Z))}
\]

where,

- \(L_i\) = measured radiance in band i
- \(L_{si}\) = deep-water radiance in band i
- \(K_i\) = attenuation coefficient for band i
- \(g\) = geometric factor to account for the path length through the water (calculated from sun and satellite zenith angles)
- \(Z\) = water depth (m)
(2) Bottom Reflectance Index (BRI)

- For this method, only **band 1** (ALOS AVNIR-2: 0.42 μm – 0.50 μm and Quickbird: 0.45 μm - 0.52 μm) and **band 2** (ALOS AVNIR-2: 0.52 μm – 0.60 μm and Quickbird: 0.52 μm - 0.60 μm) were used.

- Since band 1 has short wavelength, it will **penetrate depths better** than other band while the function of band 2 is quite similar to band 1 but it is **not as good** as band 1.

- These two bands were selected because this technique **depends on depth** itself so it makes it suitable for these two bands which are also **reliable on depth**.
\[ L_i = L_{si} + a_i R_i \exp(-K_igZ) \] (W/m²/sr)
RESULTS
RESULTS OF SUN GLINT REMOVAL

- Sun glint was applied on all visible bands (blue, green and red).
RESULTS OF SUN GLINT REMOVAL

• The slope for each visible band in the graph has been applied to the sun glint removal algorithm.

(a) with sun glint effects       (b) after removal of sun glint effects
Results of depth invariant index method

- 40 points in the water areas in each satellite scene were randomly selected to compute graph of $X_i$ versus $X_j$

![Scatter plot of sand substrate between measured radiance of band 1 and 3 from ALOS AVNIR-2]

Scatter plot of sand substrate measured radiance of band 1 and 3 from ALOS AVNIR-2

$X_i = 0.258X_3 + 2.5284$
$R^2 = 0.7683$

![Scatter plot of sand substrate between measured radiance of band 1 and 3 from Quickbird satellite data]

Scatter plot of sand substrate measured radiance of band 1 and 3 from Quickbird satellite data

$y = 0.8803x + 0.7562$
$R^2 = 0.8761$

ALOS DATA (2008)

Quickbird (2007)
RESULTS OF DEPTH INVARIANT INDEX

# Range of depth invariant index

<table>
<thead>
<tr>
<th>Satellite data</th>
<th>ALOS AVNIR-2</th>
<th>QuickBird</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seaweed</td>
<td>2.01 – 2.24</td>
<td>0.68 – 0.98</td>
</tr>
<tr>
<td>Seagrass</td>
<td>2.24 – 2.25</td>
<td>0.98 – 0.99</td>
</tr>
<tr>
<td>Coral</td>
<td>2.25 – 2.36</td>
<td>0.99 – 1.08</td>
</tr>
<tr>
<td>Sand</td>
<td>2.36 – 2.90</td>
<td>1.08 – 2.6</td>
</tr>
</tbody>
</table>
Map of sea bottom features distribution using depth invariant index method over Sibu Island for ALOS AVNIR-2 data (2008)
Map of sea bottom features distribution using depth invariant index method over Sibu Island for Quickbird data (2007)

Legend
- Seaweed
- Seagrass
- Coral Reef
- Sand
- Land
Results of bottom reflectance index

• The tidal height was considered in order to obtain the exact water depth when the satellite passes the study area which was around 10.30 am for ALOS AVNIR-2 (2008) and 11.54 am for Quickbird (2007).
• The attenuation coefficient, $K_i$, was obtained by generating the exponential graph of radiance versus depths over sand area.

Relationship between radiance and depth for band 1 and band 2 for ALOS AVNIR-2 satellite data
Relation between radiance and depth for band 1 and band 2 for Quickbird satellite data.

**Relation between radiance of band 1 and depth**

\[ y = 65.563 \exp(-0.153x) \]

\[ R^2 = 0.965 \]

**Relation between radiance of band 2 and depth**

\[ y = 95.483 \exp(-0.216x) \]

\[ R^2 = 0.9696 \]
The $K_i$ value is given below:

<table>
<thead>
<tr>
<th></th>
<th>Attenuation coefficient, $K_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Blue</td>
</tr>
<tr>
<td>ALOS AVNIR-2</td>
<td>0.0385</td>
</tr>
<tr>
<td>Quickbird</td>
<td>0.0765</td>
</tr>
</tbody>
</table>
• After obtaining the $K_i$ value, the bottom reflectance index algorithm was applied for bands 1 and 2 separately. A supervised classification based on maximum likelihood was performed in order to classify sea bottom features.
Legend
- Seaweed
- Seagrass
- Coral Reef
- Sand
- Land/Cloud

Quickbird - 2007
ANALYSIS
Analysis for depth invariant index method (ALOS AVNIR-2)

Overlay of sea truth information on ALOS AVNIR-2 processed satellite data

Legend
- Seaweed
- Seagrass
- Coral Reef
- Sand
Accuracy assessment between sea truth and classification of ALOS data over Sibu Island using depth invariant index method

<table>
<thead>
<tr>
<th>Sea Truth</th>
<th>Classification</th>
<th>Seaweed</th>
<th>Seagrass</th>
<th>Coral</th>
<th>Sand</th>
<th>Total</th>
<th>Producer Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seaweed</td>
<td>Seaweed</td>
<td>62</td>
<td>1</td>
<td>10</td>
<td>33</td>
<td>106</td>
<td>59%</td>
</tr>
<tr>
<td></td>
<td>Seagrass</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>6</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Coral</td>
<td>10</td>
<td>0</td>
<td>75</td>
<td>29</td>
<td>114</td>
<td>66%</td>
</tr>
<tr>
<td></td>
<td>Sand</td>
<td>8</td>
<td>0</td>
<td>5</td>
<td>105</td>
<td>118</td>
<td>89%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>80</td>
<td>1</td>
<td>90</td>
<td>173</td>
<td>344</td>
<td></td>
</tr>
<tr>
<td>User Accuracy</td>
<td></td>
<td>78%</td>
<td>0%</td>
<td>83%</td>
<td>61%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall Accuracy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>70%</td>
<td></td>
</tr>
<tr>
<td>Kappa Statistic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.56</td>
<td></td>
</tr>
</tbody>
</table>
Analysis for depth invariant index method using ALOS AVNIR-2 over Sibu Island

- Almost 70% of the sea truth information coincide with their own features on the classified ALOS AVNIR-2 results. Only 30% of the sea truth information did not coincide with the same features.

- Spectral confusion, limitation of spatial resolution and characteristics of features may have contributed to this problem.
Analysis for depth invariant index method (Quickbird)

Overlay of sea truth information on Quickbird processed satellite data
Accuracy assessment between sea truth and classification of Quickbird data over Sibu Island using depth invariant index method

<table>
<thead>
<tr>
<th>Sea Truth</th>
<th>Classification</th>
<th>Seaweed</th>
<th>Seagrass</th>
<th>Coral</th>
<th>Sand</th>
<th>Total</th>
<th>Producer Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seaweed</td>
<td>32</td>
<td>0</td>
<td>15</td>
<td>59</td>
<td>106</td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>Seagrass</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>6</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Coral</td>
<td>6</td>
<td>0</td>
<td>85</td>
<td>23</td>
<td>114</td>
<td>75%</td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>108</td>
<td>118</td>
<td>92%</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>45</td>
<td>0</td>
<td>105</td>
<td>194</td>
<td>344</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

User Accuracy

|                | Seaweed | Seagrass | Coral | Sand | Total | 71% | 0% | 81% | 56% |

Overall Accuracy

65%

Kappa Statistic

0.48
Analysis for depth invariant index method using Quickbird over Sibu Island

• Almost all coral features from sea truth information coincide with the coral features classified on the QuickBird data i.e. along the northwest and southeast part of the island. The result is also the same for sand.

• Overall accuracy shows only 65%. It is because the sea truth information was obtained on 18 August 2008 while the Quickbird imagery was acquired on 13 August 2007, i.e. one year difference between sea truth data and satellite data.
Analysis for bottom reflectance index method (ALOS AVNIR-2)

Overlay of sea truth information on bottom reflectance index method of ALOS AVNIR-2 processed satellite data

Legend
- Seaweed
- Seagrass
- Coral Reef
- Sand

Legend
- Sand
- Seagrass
- Seaweed
- Coral Reef
Accuracy assessment between sea truth and classification of ALOS AVNIR-2 data over Sibu Island using bottom reflectance index method

<table>
<thead>
<tr>
<th>Sea Truth</th>
<th>Classification</th>
<th>Seaweed</th>
<th>Seagrass</th>
<th>Coral</th>
<th>Sand</th>
<th>Total</th>
<th>Producer Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seaweed</td>
<td></td>
<td>76</td>
<td>0</td>
<td>13</td>
<td>17</td>
<td>106</td>
<td>72%</td>
</tr>
<tr>
<td>Seagrass</td>
<td></td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>0%</td>
</tr>
<tr>
<td>Coral</td>
<td></td>
<td>15</td>
<td>0</td>
<td>59</td>
<td>40</td>
<td>114</td>
<td>52%</td>
</tr>
<tr>
<td>Sand</td>
<td></td>
<td>4</td>
<td>0</td>
<td>23</td>
<td>91</td>
<td>118</td>
<td>77%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>95</td>
<td>0</td>
<td>99</td>
<td>150</td>
<td>344</td>
<td></td>
</tr>
<tr>
<td>User Accuracy</td>
<td></td>
<td>80%</td>
<td>0%</td>
<td>60%</td>
<td>61%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall Accuracy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>66%</td>
</tr>
<tr>
<td>Kappa Statistic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.49</td>
</tr>
</tbody>
</table>
Analysis for bottom reflectance index method using ALOS AVNIR-2 over Sibu Island

• The overall accuracy for bottom reflectance index using ALOS AVNIR-2 over Sibu Island is 66%.

• Coral reef and seaweed features were dominant at the northern and southern part of the island.

• Seagrass still cannot be detected in this method and satellite data due to limitation of spatial resolution of the satellite data.
Analysis for bottom reflectance index method (Quickbird)

Overlay of sea truth information on bottom reflectance index method of Quickbird processed satellite data.

Legend:
- Seaweed
- Seagrass
- Coral Reef
- Sand
Accuracy assessment between sea truth and classification of ALOS AVNIR-2 data over Sibu Island using bottom reflectance index method

<table>
<thead>
<tr>
<th>Sea Truth</th>
<th>Seaweed</th>
<th>Seagrass</th>
<th>Coral</th>
<th>Sand</th>
<th>Total</th>
<th>Producer Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seaweed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>106</td>
<td>39%</td>
</tr>
<tr>
<td>Seagrass</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>4</td>
<td>6</td>
<td>33%</td>
</tr>
<tr>
<td>Coral</td>
<td>7</td>
<td>0</td>
<td>75</td>
<td>32</td>
<td>114</td>
<td>66%</td>
</tr>
<tr>
<td>Sand</td>
<td>7</td>
<td>1</td>
<td>6</td>
<td>104</td>
<td>118</td>
<td>88%</td>
</tr>
<tr>
<td>Total</td>
<td>55</td>
<td>5</td>
<td>97</td>
<td>187</td>
<td>344</td>
<td></td>
</tr>
</tbody>
</table>

User Accuracy:
- 75%
- 40%
- 77%
- 56%

Overall Accuracy: 65%

Kappa Statistic: 0.47
The overall accuracy for this method using Quickbird satellite data is 65%.

Coral reef is dominating on the northern part of the island.

A few sea truth points of seagrass can be detected using this method and satellite data.
ANALYSIS

• Comparison between depth invariant index method and bottom reflectance index method of ALOS AVNIR-2 satellite data, shows that depth invariant index method gives higher accuracy compared to bottom reflectance index method.

• For Quickbird imagery, bottom reflectance index method can detect seagrass features but depth invariant index method cannot detect seagrass but it still shows higher accuracy compared to bottom reflectance index method.
• It has been noted by Sagawa et al. (2010) that depth invariant index method is suitable for very clear waters while bottom reflectance index is useful for waters of lesser water clarity. The water clarity of Sibu Island is high which makes the depth invariant index method suitable for mapping the waters of this island.

• The depth invariant index method is suitable for mapping tropical waters with high water clarity when compared to bottom reflectance index.
THANK YOU