INVESTIGATION OF ALGORITHAM TO ESTIMATE SHALLOW WATER BATHYMETRY FROM LANDSAT-8 IMAGES

Vinayaraj Poliyapram[1], Venkatesh Raghavan[1], Shinji Masumoto[2], Glejin Johnson[3] and Masita Dwi Mandini Manessa [4]

[1]Graduate School for Creative Cities, Osaka City University
3-3-138 Sugimoto, Sumiyoshi-ku, Osaka 558-8585, Japan
Email: vinay223333@gmail.com
[2]Graduate School of Science, Osaka City University
[3]National Institute of Ocanography, India
[4]Graduate School of Science and Engineering, Yamaguchi University

ABSTRACT

Information concerning water depth of near shore water region is one of the most basic requirements for coastal zone management. Bathymetry is especially important for near coastal lines, where changes can occur rapidly due to sedimentation and erosion. Here, an approach has been demonstrated to refine the shallow water bathymetry estimation algorithm using multi-spectral bands of Landsat-8 data. The approach was meant to develop a new algorithm to eliminate atmospheric and water surface components from each band and extract bottom reflectance. Short-Wave Infrared (SWI) band has been used to correct all the available bands in short wavelength in Landsat 8 data. Further, corrected bands calibrated against in-situ depth data using multiple linear regressions. The algorithm is based on assuming that the corrected bands are linearly related to the depth distribution. The proposed empirical methods are a combination of physical and statistical model that consider a constant attenuation coefficient for the study area. Depth data derived from new correction method using SWI band (1.57-1.65 µm) at Taketomi island coast, Japan and Ratnagiri, India are providing good correlation with in-situ depth data (R=0.9,0.9 and Root Mean Square Error (RMSE)=2.19m, 1.24m respectively). The correction method proposed by Lyzenga et al., (2006) using Near Infra Red (0.76-0.90µm) was also carried out and compared with our proposed method. The open and freely available high radiometric resolution Landsat-8 data can use as a reliable source for medium resolution coastal bathymetric estimation.

1. INTRODUCTION

Determination of water depths in coastal zone is a common requirement for any coastal engineering work and research related to coastal zone. For better management and protection of coastal zone, it is necessary to comprehend coastal zone conditions affected by shallow water depth data. Mapping shallow water depth data from ships by Sonar is a quite an expensive task. Many shallow water areas are not accessible by hydrographic ships due to rocks, coral reefs or simply due to inaccessibility by boats due to shallow depth of the water. Airborne Light Detection and Ranging (LIDaR) can provide complete and accurate bathymetric measurements in shallow areas, but availability of this technology is currently limited and also involves significant cost. Thus, alternative method to estimate multi-temporal depth data need to be devised and validated.

There are conflicting opinions expressed over the suitability of spectral wavelength bands for water depth estimation. Masita *et al.*, 2014, also observed that NIR band (0.77-0.89 µm) is close to the visible spectrum and still sensitive to bottom reflectance. The shallowest areas are bright even in band 4 (0.77-0.90 µm) but deeper areas (> about 15 m) are visible only in band 1 (0.45-0.52 µm) because it is just the shorter wavelengths which penetrate to the bottom (Jupp *et al.*, 1998).

Literature review revealed that bottom types and correction algorithms to eliminate atmospheric and water surface reflectance from the image are sensitive towards the bathymetry estimation. Therefore, this study made an attempt to establish a new correction method using SWI band and tested at Taketomi, Japan and Ratnagiri, India. Further the results obtained from different methods were compared and accuracy assessment for new method was carried out.

2. METHODOLOGY

The radiance observed by a satellite sensor on shallow water basically consist of four components: atmospheric scattering component, surface reflection component, in-water volume scattering component, and bottom reflection component (Kanno and Tanaka, 2012). Many authors (Baban, 1993, Muslim and Foody, 2008) observed a component of bottom reflectance in shallow water images. Bottom reflectance was transformed to depth values after removing other three components successfully.

2.1 Study area

Study areas are located at off Taketomi Island, and off Ratnagiri which lie south-eastern part of Japan and western coast of India respectively. Geographically it stretches from 124°3’00”E - 124°5’42”E and 24°18’54”N - 24° 20’42”N and 73°16’30” - 73°18’ 00”E 16° 57’ 00” -16°59’ 30”N respectively. Water quality of the Taketomi Island is clear while, water quality of Ratnagiri is not very clear and slightly turbid.

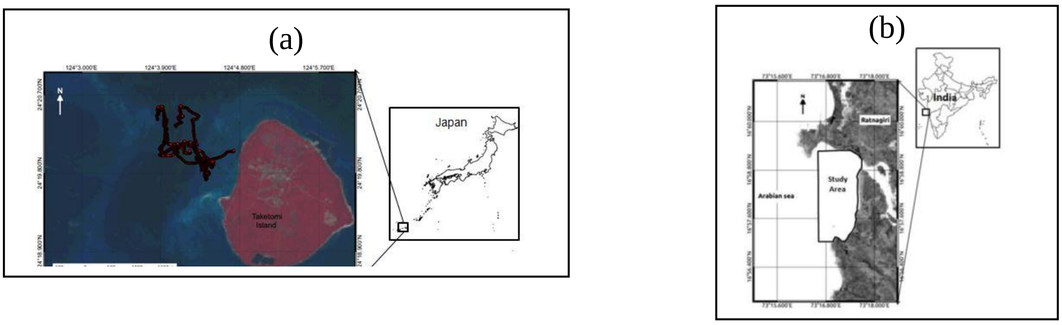

Figure 1. Study area: Taketomi Island (a) and Ratnagiri (b)

2.2 Data Used

Recently, Landsat 8 data are freely available which has high radiometric resolution quantized over a 12-bit dynamic range (This translates into 4096 potential grey levels in an image compared with only 256 grey levels in previous 8-bit instruments.). 4096 potential grey levels of Landsat 8 provide a better data for bathymetric mapping. Satellite data were already geometrically and radiometrically calibrated. Further, digital numbers are converted to physical units of band averaged spectral units (Watts/(m^2 * srad * μm)). In case of Landsat 8 the equation used to convert to radiance is

$$Radiance = MLQcal + AL \tag{1}$$

Where, *ML* is Band-specific multiplicative rescaling factor from the metadata (RADIANCE_MULT_BAND_x, where *x* is the band number), *AL* is Band-specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_x, where *x* is the band number), Qcal is Quantized and calibrated standard product pixel values (DN). In-situ depth data (m) were collected along the Taketomi Island and Ratnagiri coast. In order to match with Landsat image resolution, mean of in-situ depth data have been taken and transformed to 30 meter resolution pixels. Characteristics of the data are shown in Table 1.

Table 1. Details of data used

Data	**Date of collection**	**Tide (meters)**	**Resolution (meters)**
Landsat 8	5 April, 2014	1.37	30 (Taketomi)
In-situ depth	30 November 2014	0	1 (Taketomi)
Landsat 8	12 November, 2013	1.25	30 (Ratnagiri)
In-situ depth	17 November, 2013	2.24	7 (Ratnagiri)

2.3 Pre-processing

Implementation of all the algorithms for atmospheric correction and depth data estimation from optical remote sensing was carried out in GRASS GIS open source software (http://grass.osgeo.org/). There are two very important procedures that must be undertaken prior to bathymetric analysis. An overview of the workflow is shown in Figure. 2.

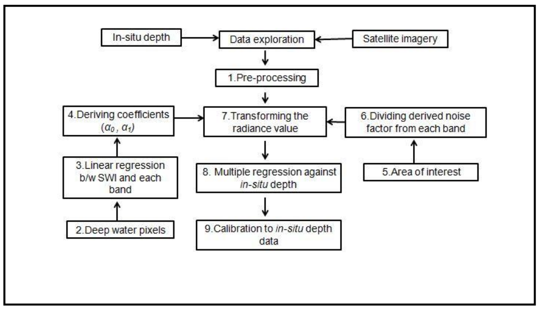

Figure 2. Flow chart of methodology

The first step is to distinguish water from the land; the ratio band2/band6 was used to classify zero values as land and greater than zero is water. Masked water region has been used for further analysis. Next step involves the correction of the imagery to remove random noise and stripping. Therefore, image smoothing with a low-pass 3*3 filters has been carried out (Step 1. in Figure 2.)

2.4 Correction using SWI band

Many authors (Lyzenga *et al.*, 2006, Kanno and Tanaka, 2006) have been established correction method by NIR band from the optical remote sensing to estimate better bathymetry from shallow water region. In contrast, we utilize SWI band to correct the atmospheric and water surface components from the image and assume that the corrected bands are linearly related to the water depth. Wang and Shi, 2007 have also established a correction algorithm utilizing SWI band in MODIS data. Subsequently, deep water pixels were determined for further processing (Step 2. in Figure 2.). Deep-water pixels are the ones where the spectral radiance for each band can be considered as corresponding to an infinite depth. The deep-water pixels have a lower overall reflectance than the shallow-water pixels, and therefore, the deep-water pixels could be easily separated by setting a threshold to on the minimum reflectance in the water region. The assumption is that water surface reflectance and atmospheric reflectance are functions of the states of waves and aerosols (atmospheric particles), respectively, and these reflectance in L(λ) are proportional to those in L(λSWI). In an area away from the shallowest waters where the product in-water volume scattering reflectance, round-trip transmittance through the atmosphere and water surface and downwelling irradiance at the top of the atmosphere is spatially homogeneous and either surface reflectance or atmospheric reflectance are represents the dominant variation, therefore we can expect a correlation between $L(\lambda)_i$ and $L(\lambda SWI)$ for an arbitrary visible wavelength λ. Further a linear regression of visible+NIR $(L\infty(\lambda)_i)$ bands against SWI band $L\infty(\lambda SWI\ )$over deep water pixels are carried out and the coefficients of regression $(\alpha 0\ (\lambda)_i\ ,\ \alpha 1\ (\lambda)_i$ were computed (step 3 and 4 in Figure 2.)

$$L\infty(\lambda)_i = \alpha_0 + \alpha_1 L(\lambda SWI\ ) \tag{2}$$

Several authors (Lyzenga, 1981, Stoffle and Halmo, 1991 and Gholamalifard *et al.*, 2013) are assuming that the actual observed radiance L(λ) varies exponentially with water depth. Also these above mentioned studies observed that there is no bottom reflectance components from deep water pixel ($L\infty(\lambda)_i$). Therefore, to extract bottom reflectance, subtraction of mean of radiance value of deep water pixels from shallow water has been carried out and logarithmically transformed to a linear function of depth by previous studies (equation 3).

$$X(\lambda)_i = log\ (L\ \lambda_i - L\infty(\lambda)_i \tag{3}$$

Where, $X(\lambda)$ is transformed band. So the value of deep water radiance $L\infty(\lambda)_i$ from equation (2) is substituted in equation (3) so the equation now transform to

$$X(\lambda)_i = log\ (L\ \lambda_i - \alpha_0 - \alpha_1\ L(\lambda SWI\ ) \tag{4}$$

This study introduces a new equation which meant to refine the correction method (step 6 and 7 in Figure 2) as follows

$$X(\lambda)_i = log\ (L\ \lambda_{i\ -}\alpha_0 - \alpha_1 L(\lambda SWI))\ /\ L\ \lambda_i\ ) \qquad 5)$$

2.4 Estimating depth from corrected multi-spectral bands.

Using the above mentioned equation (5) all visible and one NIR band were corrected. Further the corrected band radiance carried out a multiple linear regression against in-situ depth data (step 8 in the Figure). The coefficients derived from the regression analysis are used to generate a pixel wise depth over the study area.

3. RESULTS AND DISCUSSION

As mentioned in the introduction, many authors are observed bottom reflectance components in NIR region of the electromagnetic spectrum also. Therefore this study utilizes available four visible bands and one NIR band from Landsat 8 images to estimate bathymetry. The key contribution of this study is that the introduction of new correction method using SWI (1.57-1.65 µm) band. Previous studies (Lyzenga *et al*., 2006, Kanno and Tanaka, 2012) demonstrate correction method using NIR band. Since, NIR band (0.77-0.89 µm) is sensitive towards the low depth region and variety of bottom types like very bright sand bottom. But, we utilize the fact that the longer wave length bands attenuate very soon in the water region. Hence, we are expecting no reflectance components from the bottom even in low depth.

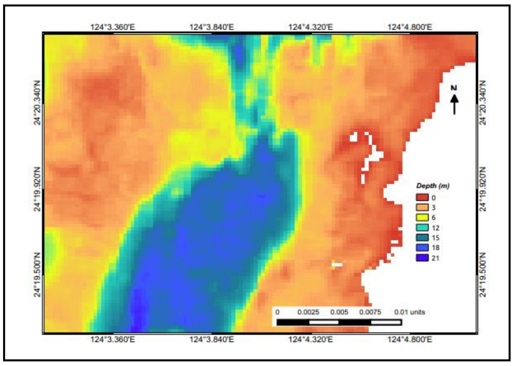

Figure 3. Bathymetry map derived from proposed method

Results derived by the SWI correction method also show good correlation with *in-situ* depth data in terms of RMSE, correlation coefficient (R) and Coefficient of determination (R^2) are at Taketomi 2.19, 0.90, 0.81 and at Ratnagiri1.24, 0.90, 0.81 respectively. In order to comprehend the outcome of the SWI band correction method, a comparative analysis was carried out with NIR band correction method and SWI correction method provides better bathymetry estimation than NIR band correction method. Details of the comparison assessment are shown in Table 2 and bivariate scatter plot shown in Figure 4.

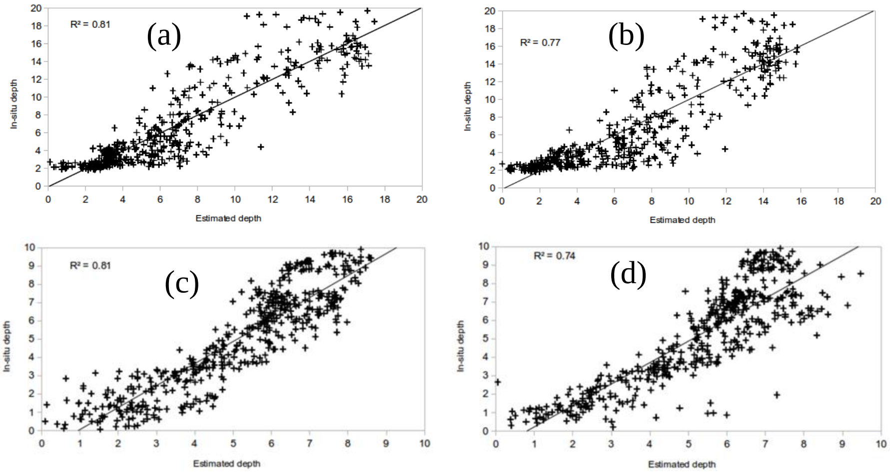

Figure 4. Bivariate scatter plots of estimated bathymetry from two different correction methods by SWI and NIR band at Taketomi (a, b), Ratnagiri (c,d) respectively.

Table 2. Comparison of results obtained from NIR band and SWI band correction methods

	Correction Method	Correlation Coefficient (R)	RMSE (meters)	Coefficient of Determination (R^2)
Taketomi	SWI	0.90	2.19	0.81
	NIR	0.87	2.42	0.77
Ratnagiri	SWI	0.90	1.24	0.81
	NIR	0.85	1.38	0.74

4. CONCLUSIONS

Optical satellite derived bathymetry studies have been carried out from decades. Recently authors have investigated different correction methods using NIR band. This study proposes a new method using SWI band to overcome the problems occurred due to NIR band correction in Landsat 8 images. Mainly two observations are made, NIR band also contains bottom reflectance at low depth and places were high bottom reflectance in NIR region. However, this study is relying on the fact that there is no bottom reflectance component is contained in SWI band. Therefore, SWI band was used to correct the atmospheric and water surface components from other bands. The comparative study also observed that particular places where NIR band correction method provides null values due to high bottom reflectance in NIR region. The alternative correction method using SWI provides depth data where NIR correction method is not able to provide a bathymetric estimate. This study concludes that freely available high radiometric resolution Landsat 8 data can provide good accuracy bathymetry estimation using SWI band correction method.

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