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Assessing WorldView-2 Satellite Imagery Accuracy for Bathymetry Mapping in Pahawang Island, Lampung, Indonesia

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Abstract. Bathymetry is one of a vital marine geospatial data which is required in many hydrographic analysis. The extent of remote sensing gives a possibility of advancement even onto bathymetry modeling. The visible electromagnetic spectrum gives different reflectance intensity in various sea depth due to attenuation processes. This peculiar spectral responses is then used as the basis of bathymetry modeling using satellite imagery. This paper's goal is to test the WorldView-2 ability for bathymetry mapping in Pahawang Island, Lampung, Indonesia. The WorldView-2 Image of Pahawang Island is corrected into top of atmospheric (ToA) reflectance. It is then being analyzed using bivariate statistic (linear, exponential, and polynomial regression) along with the tide-corrected sea depth data which is acquired from field survey using GPSMAP 840xs single beam in a sampling framework. We then perform a standard error method to determine the most effective result of bathymetry model by its accuracy value.

Keywords : Bathymetry, WorldView-2, ToA, Regression, Standard Error

1. Introduction

Bathymetry is the technique used to measure and explore the depth of the water bodies covering the majority of the earth surface. The earliest systematic bathymetry data acquisition was conducted in 1845 by U.S. Coast Survey in Gulf Stream while the first bathymetry map was published by Maury in the 1853 Wind and Current Charts of the North Atlantic Ocean [1]. The seafloor mapping plays important role in oceanographic study. Those early bathymetry mapping has lead to many important discovery such as the exposal of Mid-Atlantic Ridge and the indication of Mariana Trench. Later on, bathymetry data acquisition also becomes a trend when dealing with the shallow water environtment analysis.

The basic method of bathymetry data acquisition was conducted by using a manual-match transect sampling framework in several decided line. The depth data was retreieved by weighted flax rope which was dropped over the side of a vessel and the length of the line recorded once the weight reached the bottom. Despite the difficult fieldwork activity, this traditional bathymetry data acquisition method has a big issue regarding the accuracy. The internal current force causing the flax to drift and resulting in the depth overestimate. As the technology develops, this problem was also tackled by the development of digital bathymetry data acquisition method. It is now possible to conduct an efficient bathymetry survey using acoustic, radar, and electromagnetic instrument [2].

Pahawang Island in Lampung, Indonesia is located between 5º41’53”-5º39’02”S and 105º11’44”-105º14’59” E. It has approximately 3,3 km^2 area surrounded by quite massive shallow water ecosystem. It is mainly consisted of coral reefs, sea grass, algae, and countless benthic organism [3]. In the framework of sustainable marine conservation, bathymetry becomes one essential data to monitor and evaluate ecosystem condition. But, some believe that conventional bathymetry survey (through traditional or acoustic method) is considered ineffective because it takes a lot of time and work to do the field survey.

Meanwhile, WorldView-2 satellite imagery as a product of electromagnetic remote sensing indicates a great potential to do this task. The spectral resolution containing coastal (400-450 nm), blue (450-510 nm), green (510-580 nm), yellow (585-625 nm), red (630-690 nm), red-edge (705-745 nm) and two near infrared (770-895 and 860-1040 nm) has a great capability to perform various technique involving several band combination. Besides, satellite imagery pixel contain unique and important values which could be derived into so many type of data with a relatively wide area. Not to mention WorldView-2 has a high resolution pixel that has a good chance in modelling the bathymetry with reasonable accuracy. It is also efficient to assess a lot type of data with a minimum requirement of fieldwork. This paper’s focus is to produce an equation to transform digital number in WorldView-2 raster into depth data through several image processing and statistical procedure. We also perform a certain method to assess the final bathymetry result to justify the relevance and show the error margin.

2. Data and Method

2.1 Data

We use standard equipment for bathymetry survey with echosounder GPS map 2108 as the main tool. Meanwhile, we use WorldView-2 imagery provided by The DigitalGlobe Foundation as the modeling base to produce bathymethry maping. WorldView-2 imagery that used in this research is recorded on August, 3rd 2015. This imagery has six visible bands, which is coastal (400-450 nm), blue (450-510 nm), green (510-580 nm), yellow (585-625 nm), red (630-690 nm), and red-edge (705-745 nm) and two near infrared (770-895 and 860-1040 nm). WorldView-2 imagery has 16-bit radiometric resolution and 1.8 m spatial resolution. To handle WorldView-2 imagery, we use ENVI software by Harris Geospatial. Acording to [4], log-transformed band have high accuracy value at Bathymetry modeling. This fact was also proved by [5] which stating that the best accuracy value of their bathymetry modelling was produced by log transformed blue/green band.

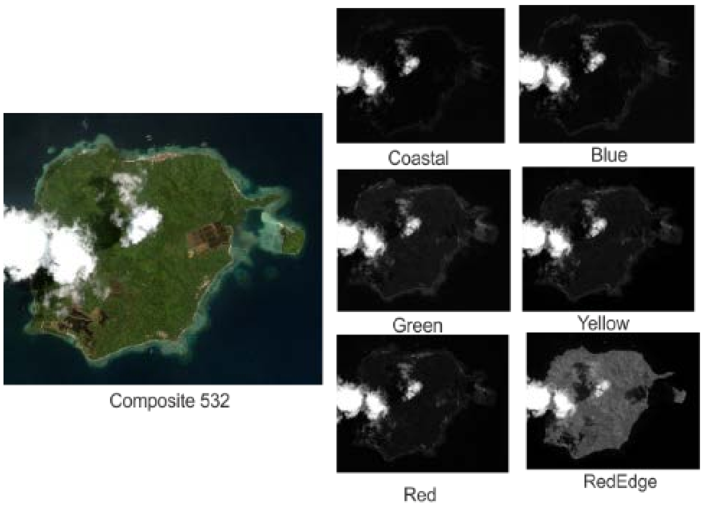

Figure 1. Visible Band of WorldView-2 Imagery

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2.2 Method

2.2.1 Image Correction. Image correction used in this study is atmospheric correction. This correction useful for improving the pixel value from atmospheric disturbance in order to match the pixel value with the object reflectance value. The radiometric corrections should be done by considering atmospheric disturbance factors as the main source of error [6]. The atmospheric correction is done by converting the WV2 pixel value to the at sensor value reflectance [7] and then removes the radiance path by the Dark Subtract method [8].

2.2.2 Single Band Method. Single band method that we use to build bathymetry empirical model depends on water depth and has been corrected until atmospheric level. The attenuation of waves will stronger along the increase of water depth. Water depth variation in study area and wavelength must be noticed by observer. Band that most effective to attenuate energy uses to build bathymetry model. After that, exponent empirical model of single band will be compared with log-transformed single band to see linearization process. Spectral reflection and water depth linearization will effect and increase bathymetry model accuracy.

2.2.3 Ratio Band Method. Electromagnetic wave energy at water colomn influenced by depth variable because the energy will fall of with increasing depth. Variation of existing cover at the bottom of water does not have an effect on depth variable [9], but influences to difference in spectral reflection. In a sense, independent depth information with other variables, so on bathymetry modeling band ratio method becomes a solution to accommodate this fact ([10]; [11]; [4]). In this study, band ratio method was performed on three bands original that is coastal band, Blue band, green band and log-transformed band of WorldView-2 Imagery, the total there are 11 bands.

2.2.4 Empirical Modeling. Empirical bathymetry modeling is done by using R_w WorldView 2 imagery and Z value with looking for relationship between both of them. Z value are obtained from field survei measurement using echosounder. The total sample from field survei were 247, 122 were used for test accuracy and 125 were used for modeling sample. Modeling begins with correlation analysis to obtain correlation coefficient (r) value. All of bands as a materials for input in empirical modeling using regression analysis. To do so, we use regression as a kind of bivariate statistical analysis technique there are three type of regression for bathymetry modeling : *linear regression, power regression,* and *exponential regression*. The dependent variable for those regression is pixel value in 11 band from 3 single band, 4 ratio band and 4 log transformed band, while the independent variable is the training sample consisted of bathymetry survey.

2.2.5 Accuracy Test. Coeficient value (r) and regression value (R^2) canot be evaluate acuracy value, so that why standart Error of Estimate (SE) used for evaluate acuracy from bathymetry modeling. The sample used for accuracy test is an unused sample in modeling. Sample used for test accuracy were 122 from 247 total sample field survey.

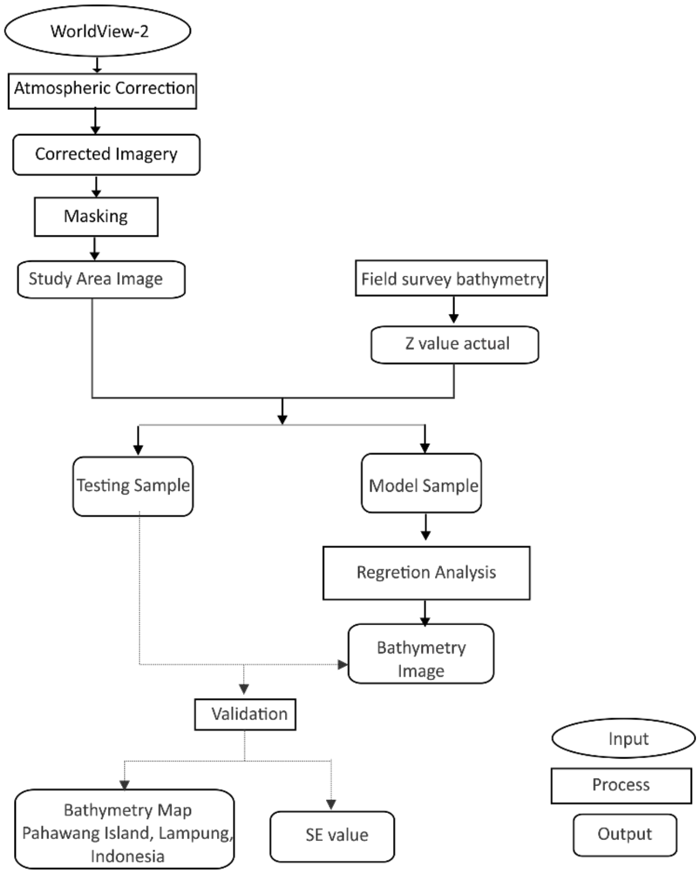

Figure 2. *Flow Chart*

3. Result and Discussion

3.1 Regression Model

The change of spectral value to depth data uses formula referred to [4]. The equation is equal to y = ax + b, where *mi* is the value of *a*, *m0* is the value of *b*, and the value of *x* is the spectral band to be used.

$$Z = m1\ Rw \times m0 \tag{1}$$

Table 1. Bathymetry Regression Model

Band		Linier	R^2	Exponen	R^2	Power	R^2
Single Band	*Coastal*	y = -232.23x + 43.721	0.0652	$y = 47510e^{-57.13x}$	0.0306	$y = 6E\text{-}08x^{-9.976}$	0.031
	Blue	y = -66.679x + 13.956	0.0272	$y = 61.6e^{-20.72x}$	0.0204	$y = 0.0048x^{-3.355}$	0.0213
	Green	y = -187.2x + 25.7	0.4418	$y = 8758e^{-69.22x}$	0.4692	$y = 4E\text{-}08x^{-8.387}$	0.4766
Ratio Band	*Coastal/Blue*	y = 7.6492x - 4.9376	0.0083	$y = 0.0601e^{3.333x}$	0.0122	$y = 1.6681x^{3.62=24}$	0.0119
	Blue/Coastal	y = -9.3552x + 11.988	0.0084	$y = 84.255e^{-3.932x}$	0.0116	$y = 1.6676x^{-3.625}$	0.0119
	Blue/Green	y = 34.186x - 41.709	0.7888	$y = 1E\text{-}07e^{12.641x}$	0.8375	$y = 0.0234x^{16.628}$	0.8393
	Green/Blue	y = -57.739x + 47.287	0.7591	$y = 4E{+}07e^{-21.79x}$	0.8395	$y = 0.0234x^{-16.63}$	0.8394
Log Transfor	*(ln) Coastal/Blue*	y = -15.505x + 18.196	0.0071	$y = 1421.3e^{-6.746x}$	0.0105	$y = 1.6792x^{-6.451}$	0.0106

Band		Linier	R^2	Exponen	R^2	Power	R^2
m Ratio Band	*(ln) Blue/Coastal*	y = 13.892x - 11.161	0.007	$y = 0.0035e^{6.1804x}$	0.0108	$y = 1.6776x^{6.4676}$	0.0107
	(ln) Blue/Green	y = -113.02x + 101.88	0.7819	$y = 4E+16e^{-42.86x}$	0.873	$y = 0.0131x^{-37.44}$	0.8731
	(ln) Green/Blue	y = 86.995x - 96.498	0.7958	$y = 1E-16e^{32.696x}$	0.873	$y = 0.0131x^{37.453}$	0.8733

3.2 Single Band

Bathymetric modeling using single band analysis shows that the WorldView-2 visible band has a negative relation with the depth value, the spectral reflectance value would be decreased as the depth increases. The results of bathymetric modeling using single band has the highest determinant coefficient (R^2) value of 0.4766 on the green band.

This corresponds to [4] research, that the green band has a good capability in penetration in shallow water. Therefore the use of green bands can improve accuracy in shallow water applications (bathymetry) compared to other single bands. Bathymetry modeling using a single band has problems, due to the influence of various bottom object reflectance, so the correlation between single band pixel value with the depth value becomes low [12].

Table 2. Accuracy and SE value of Single Band

Band		Liniear		Exponent		Power	
		Accuracy %	SE	Accuracy %	SE	Accuracy %	SE
Single Band	*Coastal*	31.798	3.130	24.271	3.476	24.031	3.487
	Blue	31.788	3.131	23.837	3.496	24.082	3.484
	Green	50.505	2.272	48.763	2.352	50.108	2.290

Regression function in single band shows best linear equation on green band with value of SE 2.272 and accuracy 50.505% with equation y = -187.2x + 25.7. The value of SE 2,272 shows the difference of 2,727 meters between bathymetric modeling with actual depth condition.

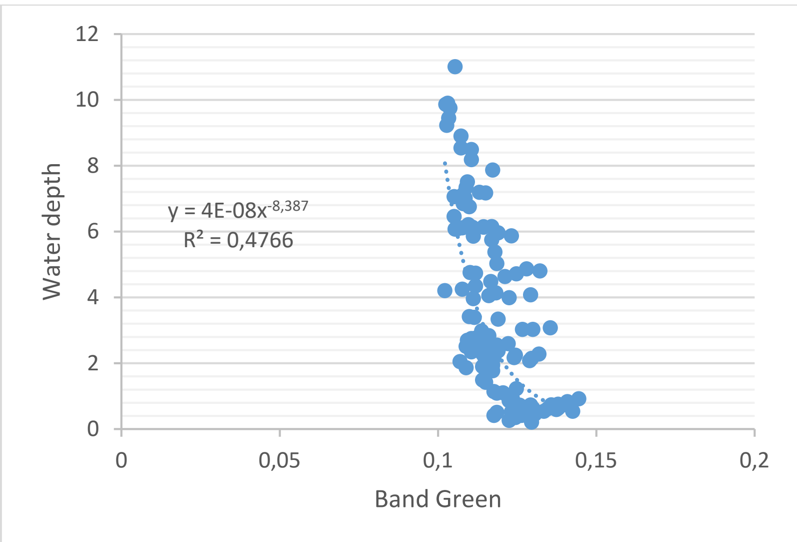

Figure 3. Regression Model of Band Green

3.3 Ratio Band

The application of band ratios is used to normalize the reflections of the water column due to the effects of the various bottom object reflectance. The Ln (Log-transform) function in each image is used to linearize relation between the depth value with the image pixel value. The combination of band ratio used for modeling has a relationship with depth value. The result of bathymetric modeling with the highest determinant coefficient (R^2) value in Band ratio of original band is 0.8395 using Band Green / Band Blue, and the highest determinant coefficient (R^2) value in Band ratio of log transform band is 0.873 in Ln Blue / Ln Green band. In band ratio of original band, has highest accuracy or lowest SE value which obtained through the ratio of log transformed ratio band of Ln band blue / Ln band green that is 72.313% and 1,271 meters. The highest accuracy bathymetric modeling result, obtained through the log transformed ratio band Ln band blue / Ln band green of 72.675% and with SE of 1,254 meters.

Table 3. Accuracy and SE value of Ratio Band

Band		Liniear		Exponent		Power	
		Accuracy %	SE	Accuracy %	SE	Accuracy %	SE
Band Ratio	*Coastal/Blue*	31.378	3.150	23.446	3.514	23.448	3.513
	Blue/Coastal	31.371	3.150	23.451	3.513	23.448	3.513
	Blue/Green	70.056	1.374	62.654	1.714	71.868	1.291
	Green/Blue	67.673	1.484	72.313	1.271	71.847	1.292
Log Transform Band Ratio	*(ln) Coastal/Blue*	31.323	3.152	23.413	3.515	23.409	3.515
	(ln) Blue/Coastal	31.324	3.152	23.480	3.512	23.409	3.515
	(ln) Blue/Green	68.542	1.444	72.675	1.254	72.455	1.264
	(ln) Green/Blue	69.652	1.393	70.465	1.356	72.429	1.265

Regression function in band ratio shows best equation on log transformed ratio band Ln band blue / Ln band green with value of SE 1.264 and accuracy 72.455% with power regression equation $y = 0.0131x^{-37.44}$. The value of SE 1.264 shows the difference of 1.264 meters between bathymetric modeling with actual depth condition.

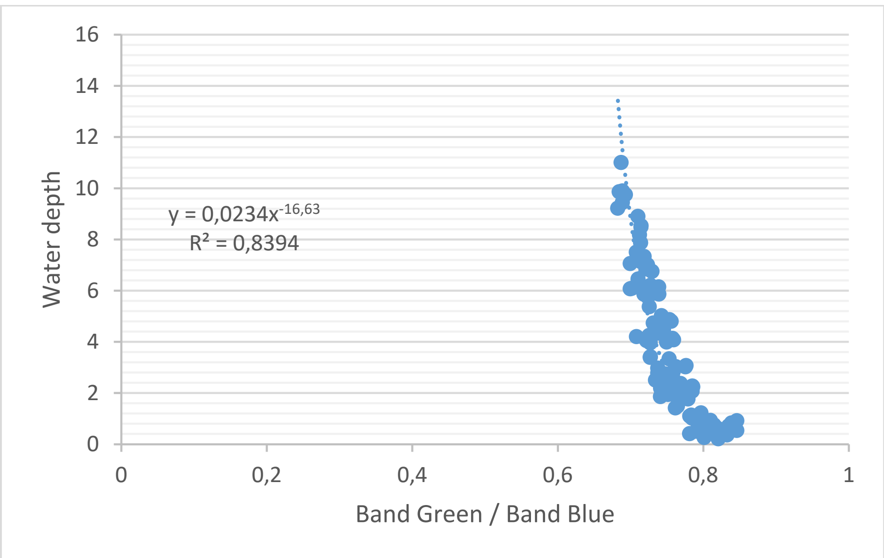

Figure 4. Ratio Band of original band (Band Green/Band Blue)

The curve above show that ratio band green/ blue have negative relationship between the pixel value and depth value, same as bathymetry model using single Green band.

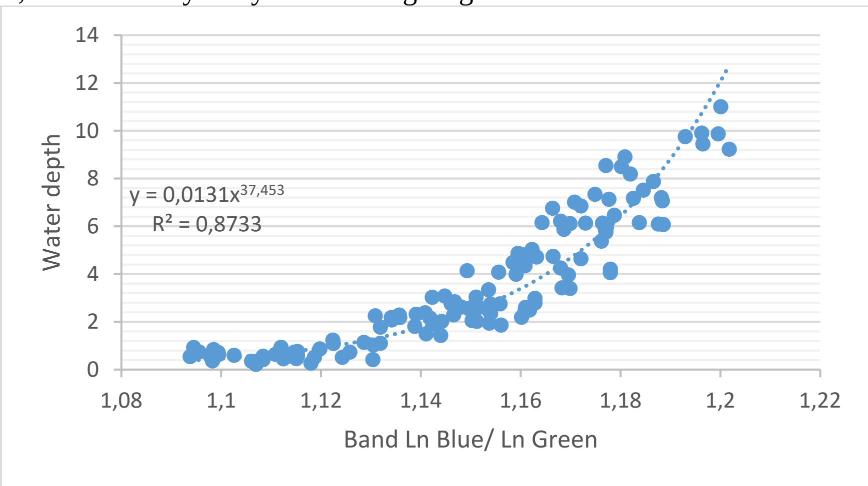

Figure 5. Log transformed ratio band Ln band blue / Ln band green

The log-transformed ratio band regression curve above proves that log transformed band can linearize relation between depth value and exponential pixel value.

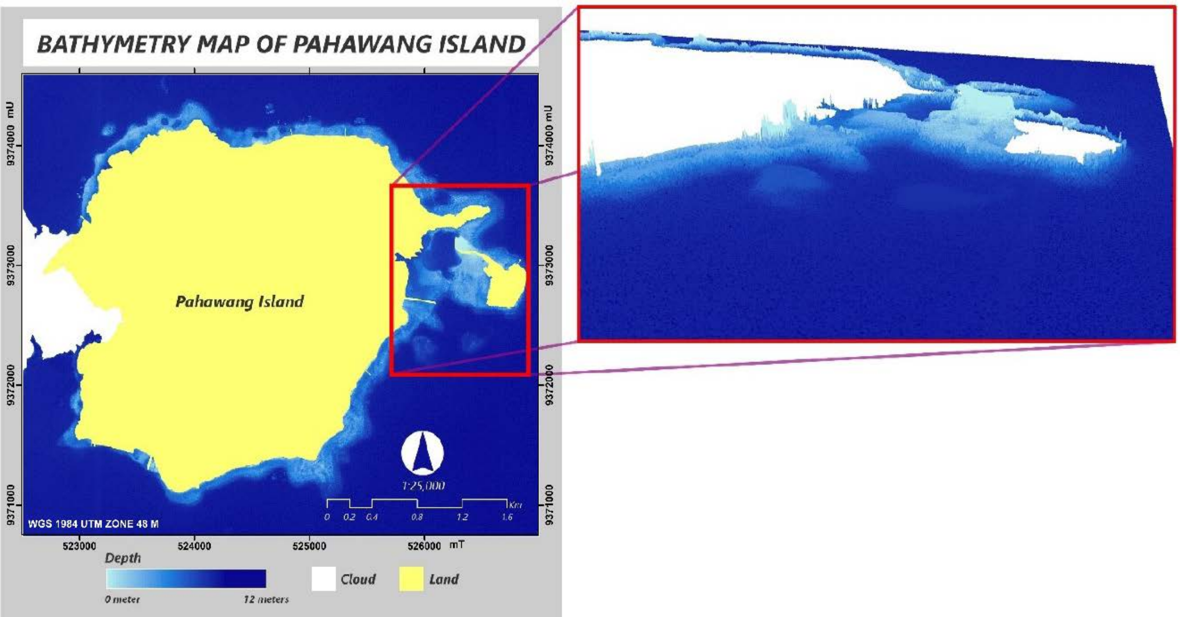

Figure 6. Bathymetry Map

4. Conclussion

The basic method of bathymetry data acquisition was conducted by using weighted flax rope which was dropped over the side of a vessel and the length of the line recorded once the weight reached the bottom. Despite the difficult fieldwork activity, this traditional bathymetry data acquisition method has a big issue regarding the accuracy. The internal current force causing the flax to drift and resulting in the depth overestimate. As the technology develops, this problem was tackled by the development of digital bathymetry data acquisition method including the satellite imagery. We try to assess WorldView-2 image capability for bathymetry modelling in Pahawang Island, Lampung, Indonesia. We perform standard atmospheric correction to gain pixel ToA value. Method used for bathymetry modeling is single band and ratio band, the highest accuracy 50.505% using single band method for green band, highest accuracy for band ratio is Band Green / Band Blue and log transformed ratio band Ln band blue / Ln band green of 72.675% . Bathymetry modeling in Pahawang Island Lampung can show the depth variation up to + 14 meters.

References

[1] Heidi M Dierssen and Albert E. Theberge 2014 *Bathymetry: History of Seafloor Mapping* (Encyclopedia of Natural Resources vol II – Water and Air) ed Yeqiao Wang (Taylor & Francis Group) pp 1-6
[2] Harper Jeremy 2015 *Bathymetry Concepts and Aplication* (US: Callisto Reference)
[3] Lazuardi W, Hakim L, Astuty I S, Al Hadi A, Hermayani R, Pratama D N and Dewi A C 2017 Coral Health Assessment Using WorldView-2 Satellite Imagery In Pahawang Island Lampung Indonesia (Seminar Nasional Geomatika 2017)
[4] Wicaksono P 2010 Integrated Model of Water Column Correction Technique for Improving Satellite-based Benthic Habitat Mapping, A Case Study on Part of Karimunjawa Islands, Indonesia. Universitas Gadjah Mada (Yogyakarta: Faculty of Geography)
[5] Nurkhayati R and Khakhim N 2013 Pemetaan Batimetri Perairan Dangkal Menggunakan Citra Quickbird di Perairan Taman Nasional Karimun Jawa Kabupaten Jepara Jawa Tengah. *Jurnal Bumi Indonesia*
[6] Danoedoro P 2012 *Introduction to Digital Remote Sensing* (Yogyakarta: Penerbit Andi)
[7] Updike T and Comp C 2010 *Radiometric Use of WorldView-2 Imagery* (Longmont, Colorado: DigitalGlobe®)
[8] Armstrong R A 1993 Remote sensing of submerged vegetation canopies for biomass estimation *International Journal of Remote Sensing*. vol **14** p 10-16
[9] Lyzenga D R 1978 Passive Remote-Sensing Techniques for Mapping Water Depth and Bottom Features. *Applied Optics* vol **17** p 379-383.
[10] Hogrefe K R 2005 Deriving Shallow Water Bathymetric Data from Ratios of Blue and Green λ Radiance Values. Oregon: Department of Geosciences (Oregon State University)
[11] Stumpf R P, Holderied K and Sinclair M 2003 Determination of water depth with high-resolution satellite imagery over variable bottom types. *Limnology and* Oceanography Vol **26** p 547-556.
[12] Jupp D L 1988 Background and extensions to depth of penetration (DOP) mapping in shallow coastal waters *Proc., Symp., Remote Sensing of the Coastal Zone.* (Gold Coast : Queensland)

Acknowledgements

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