International Journal of Remote Sensing and Earth Sciences Vol.10 No.1 June 2013:1-8

DERIVING INHERENT OPTICAL PROPERTIES FROM MERIS IMAGERY AND *IN SITU* MEASUREMENT USING QUASI-ANALYTICAL ALGORITHM

Wiwin Ambarwulan[1*], Widiatmaka[2], and Syarif Budhiman[3]
[1]Geospatial Information Agency, Cibinong, Indonesia
[2] Dept. of Soil Science, Bogor Agricultural University, Bogor, Indonesia
[3] National Institute of Aeronautics and Space, Jakarta, Indonesia
[*]e-mail: wiwin.ambarwulan@big.go.id; w_ambarwulan@yahoo.com

Abstract. The paper describes inherent optical properties (IOP) of the Berau coastal waters derived from *in situ* measurements and Medium Resolution Imaging Spectrometer (MERIS) satellite data. Field measurements of optical water, total suspended matter (TSM), and chlorophyll-a (Chl-a) concentrations were carried out during the dry season of 2007. During this periode, only four MERIS data were coincided with *in situ* measurements on 31 August 2007. The MERIS top-of-atmosphere radiances were atmospherically corrected using the MODTRAN radiative transfer model. The *in situ* optical measurement have been processed into apparent optical properties (AOP) and sub surface irradiance. The remote sensing reflectance of *in situ* measurement as well as MERIS data were inverted into the IOP using quasi-analytical algorithm (QAA). The result indicated that coefficient of determination (R^2) of backscattering coefficients of suspended particles (b_{bp}) increased with increasing wavelength, however the R^2 of absorption spectra of phytoplankton (a_{ph}) decreased with increasing wavelength.

Keywords: *QAA, MODTRAN, MERIS, Remote sensing reflectance, Berau estuary water*

1 INTRODUCTION

The Berau estuary, East Kalimantan, is a high biodiversity site in Indonesia that has been declared as a Marine Protected Area (MPA) by the Indonesian government. Mapping of suspended sediment concentration and water transparency are essential for monitoring the health of the ecosystem and especially of coral reefs. In this study area, the coral reef ecosystem is located at 40 to 100 km from the mouth of the Berau river. Water quality monitoring in this environment becomes increasingly important because there are enhanced anthropogenic activities in the Berau catchment such as coal mining and deforestation whichhave increased the load of suspended sediment, chemicals, and nutrients into the estuary. Mapping of total suspended matter distribution as well as Chl-a concentration using an accurate methodology will help the coastal manager to arrange the plan of environmental protection in order to sustain the MPA program.

Remotely sensed imageries play an important role in coastal area management, by providing the synoptic view of landscape. Such view is practically impossible to be obtained by conventional *in situ* measurements. Ocean color remote sensing applications utilize the spectral characteristics and variations of radiometric data to derive information about some of the constituents of the water. Techniques for water constituent retrieval have evolved from an empirical to the semi-analytical approach. The empirical algorithms (Gordon & Morel, 1983) only capable retrieving a single constituent concentration. The semi-analytical method is capable in retrieving three water constituents simultaneously.

The color of the ocean, as detected from above, depends strongly on the inherent optical properties (IOPs) of the upper water column. Inherent optical properties (IOPs) are the optical properties of water that are independent of the ambient light field (Preisendorfer, 1976). Scattering and absorption coefficients are some example of IOPs paramaters affected by water constituent such as suspended and dissolved organic materials. Variations in IOPs are clear indications of changes in water characteristics. The apparent optical properties (AOPs), are those optical properties that are influenced by the angular distribution of the light field, as well as by the nature and quantity of substances present in the medium. The AOPs parameters are diffuse attenuation coefficients (K_d), as well as subsurface irradiance reflectance $R(0^-)$, remote sensing reflectance (R_{rs}). Various models have been developed to relate IOPs and AOPs (IOCCG, 2006). Salama *et al.* (2009) developed an algorithm, modified from the GSM semi-analytical model, for deriving bio-optical properties such as IOPs in inland waters. Ambarwulan *et al*. (2011) studied the specific inherent optical properties of Berau water using Bio-Optical Model Inversion.

The total absorption coefficient $a(\lambda)$ and total backscattering coefficient $b_b(\lambda)$ are the basic IOPs in ocean color remote sensing, which are the key to connect AOPs from the remote sensor and the concentration of water component. Multi-band quasi-analytical algorithm (QAA) developed by Lee *et al.* (2002) to retrieve absorption and backscattering coefficients, as well as absorption coefficient of phytoplankton pigments and CDOM have been used in this study. The main idea of QAA was to calculate optical properties in a level-by-level scheme. Firstly, the values of total absorption and backscattering coefficients were analytically calculated from values of remote-sensing reflectance. Then, phytoplankton and CDOM coefficients were decomposed from the total absorption coefficients. The goal of this research was to retrieve IOPs from MERIS data using QAA and Case-2 Regional Algorithm.

2 MATERIALS AND METHODS

2.1 The study area

The study area is Berau Estuary waters, situated in east Kalimantan and the northern Makassar straits affected by the Indonesian Through-Flow (ITF) (Figure 1). The ITF affects the predominant along-shore current in East Kalimantan coastal waters in southward direction through the Makassar straits. The area is also influenced by tidal (semi-diurnal), seasonal (monsoon), and intra-annual effects. The Berau coral reef and atolls system are distributed north from the Berau delta. From the land side, the Berau river accounts for a substantial amount of annual fresh water and sediment input into the coastal zone. Thus, studying the coastal dynamics in the Berau estuary is very interesting due to its relative small area, but it is composed of a complex ecosystem and processes.

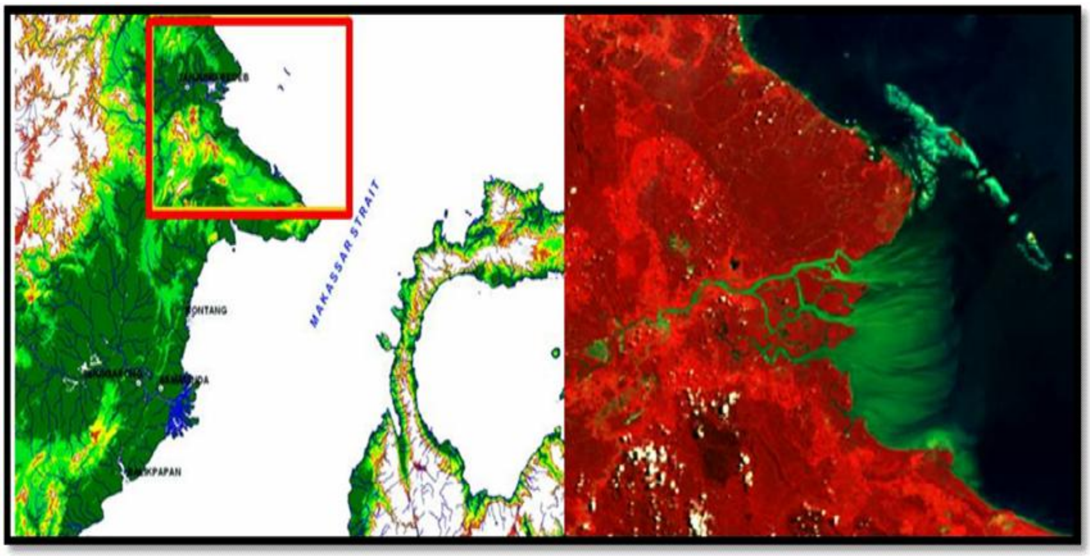

Figure 1. The Berau Estuary, East Kalimantan, Indonesia

2.2 *In situ* observations

The *in situ* observations involved water sampling, in-water radiometer measurements (using Ocean Optic Spectrometer - USB4000), and Secchi disk depth measurement for transparency of light. Bio-geophysical parameters were also measured using a Horiba U10 water quality multi-sensor probe forconductivity, temperature, pH, turbidity, dissolved oxygen, and salinity. The observations were carried out during August - September 2007. From each station, water sample was collected. Under and above water radiometric measurements were carried out using the Ocean Optic Spectrometer USB4000. Spectra of subsurface irradiance were measured at three depths of 10, 30 and 50 cm. The subsurface irradiance reflectance R(0-), was then calculated from the measured subsurface irradiance spectra at 10, 30, and 50 cm depth. The water sampling and radiometer observations were always conducted from the area where the was no shadow of the boat.

2.3 The AOP generated through water sample analysis

The above surface remote sensing reflectance (R_{rs}) was an input on the estimation IOP using QAA. The R_{rs} of *in situ* optical measurement obtained from the subsurface irradiance reflectance $R(\lambda,0\text{-})$ at each wavelength (λ) was calculated. The $R(0\text{-})$ was one of AOP parameters as the ratio of upward (E_u) and downward (E_d) irradiance (µWcm-2nm-1) just beneath the water surface (Mobley, 1994). The subsurface remote sensing reflectance was calculated as ratio between the subsurface irradiance reflectance and Q (geometric anisotropy factor of the underwater light field). It was usually taken as Q = 5 sr (Gege, 2005). From the subsurface remote sensing reflectance, the above surface remote sensing reflectance was calculated by multiple $R_{rs}(0\text{-})$ with 0.544 (Bhatti *et al.,* 2009).

2.4 The AOP retrieved from MERIS imagery

The remotely sensed imagery used in this study was Medium Resolution Imaging Spectrometer (MERIS). The MERIS Level 1b (L1b) and Level 2 (L2) were provided by the European Space Agency (ESA). The MERIS recorded on August 31, 2007 was used in this study. The above surface remote sensing reflectance $R_{rs}(0^+)$ of MERIS data was derived with different atmospheric correction methods. A radiative transfer models MODerate spectral resolution atmospheric TRANsmittance (MODTRAN) for atmospheric simulation and correction was applied in this study (Berk *et al.,* 2000). The Case-2 Regional algorithm processor (C2R) (Doerffer and Schiller, 2007) and the Free University of Berlin algorithm processor (FUB) (Schroeder and Schaale, 2005) were Case-2 plug-in algorithms in BEAM Visat, and they were based on an artificial neural network trained on the basis of radiative transfer model calculations. The main task of these algorithms was to retrieve the top-of-water (TOW) reflectance from the top-of-atmosphere (TOA) reflectance derived from the radiance measured by the satellite sensor.

2.5 Deriving inherent optical properties from model inversion

The IOPs of Berau estuary waters were derived using QAA. The R_{rs} *in situ* measurement and R_{rs} MERIS were input in the QAA. The subsurface remote sensing reflectance (r_{rs}) in this study was calculated based on a function of $r_{rs}(\lambda) = R_{rs}(\lambda)/(0.52 + 1.7R_{rs}(\lambda))$ (Lee *at al., 2002).* A full description of the QAA was presented by Lee *et al.* (2002) and IOCCG (2006) and Lee *et al*. (2010). Briefly, the QAA employs a series of analytical, semi-analytical and empirical algorithms to convert $r_{rs}(\lambda)$ to $a(\lambda)$, and $b_b(\lambda)$. The absorption coefficient $(a(\lambda))$ was decomposed into seawater absorption, $a_w(\lambda)$, phytoplankton absorption, $a_{ph}(\lambda)$, and the combined absorption of coloured detrital and dissolved material (CDM), $a_{dg}(\lambda)$ (considered together as a single term because of their similar spectral shapes (Nelson *et al.,* 1998; Nelson and Siegel, 2002). The backscattering coefficient $(b_b(\lambda))$ was partitioned into terms due to seawater, $b_{bw}(\lambda)$, and suspended particulates, $b_{bp}(\lambda)$. The retrieved IOPs using

QAA include *a(λ)*, $b_{bp}(\lambda)$, $a_{ph}(\lambda)$, and $a_{dg}(\lambda)$ of wavelengths r_{rs} values at 410, 440, 490, 510, 555, and 670 nm.

3 RESULTS AND DISCUSSION

3.1 Retrieving IOPs using QAA

The QAA algorithms steps to retrieve IOPs from R_{rs} were applied to the *in situ* data sets and MERIS data set. The IOPs retrieved using QAA from R_{rs} *in situ* measurement and R_{rs} MERIS data was displayed in Table 1. In general, derived values of b_{bp} water are in the range found by previous study. Ambarwulan *et al.* (2011) found the backscattering of suspended sediment (b_{bp}) of the Berau estuary water using Bio-optical model inversion ranged at the value from clear to turbid water (b_{bp}=0,019 - 0,604 m^{-1}).

The backscattering coefficients of suspended particles b_{bp} of R_{rs} of *in situ* measurement and R_{rs} MERIS data showed that the highest value of the b_{bp} was obtained in the short wavelength and continually decreases with increasing wavelength (Table 1). The b_{bp} derived from R_{rs} MERIS data was higher compared to the b_{bp} derived from R_{rs} *in situ* measurement. The difference between *in situ* measurement and MERIS data could also be due to the within-pixel heterogeneity. The *in situ* measurements were obtained at point locations that represent a very small homogenous water footprint, while the MERIS sensor records the signal over a much larger 1.44 km^2 water surface area (1.2 km resolution RR data).

Table 1. The IOPs of the Berau Estuary waters retrieval from *in situ* and MERIS data using QAA.

IOP (m-^{1})		410		440		490		510		560	
		In Situ	MERIS	*In Situ*	MERIS	*In Situ*	MERIS	*In Situ*	MERIS	*In Situ*	MERIS
	min	0,0078	0,0161	0,0067	0,0139	0,0053	0,0112	0,0049	0,0103	0,0040	0,0085
bbp	max	0,2219	0,6986	0,2145	0,6427	0,2037	0,5659	0,1999	0,5398	0,1911	0,4834
	mean	0,0549	0,1111	0,0511	0,1013	0,0459	0,0880	0,0441	0,0836	0,0403	0,0740
	min	0,0264	0,0422	0,0314	0,0354	0,0338	0,0466	0,0479	0,0507	0,0656	0,0692
	max	0,8739	0,2253	0,7945	0,1857	0,6458	0,2051	0,5338	0,1828	0,3152	0,1486
a	mean	0,1582	0,1053	0,1696	0,0857	0,1767	0,0970	0,1604	0,0914	0,1239	0,0936
	min	-0,0794	0,0304	-0,0506	0,0194	-0,0239	0,0092	-0,0177	0,0068	-0,0084	0,0032
	max	0,5330	0,1705	0,3399	0,1087	0,1605	0,0513	0,1189	0,0380	0,0562	0,0180
adg	mean	0,0608	0,0794	0,0388	0,0506	0,0183	0,0239	0,0136	0,0177	0,0064	0,0084
	min	0,0123	0,0070	0,0170	0,0097	0,0149	0,0225	0,0126	0,0114	0,0024	0,0041
	max	0,3424	0,0545	0,4594	0,0734	0,6547	0,1401	0,5190	0,1132	0,2617	0,0692
aph	mean	0,0927	0,0211	0,1245	0,0287	0,1397	0,0581	0,1115	0,0411	0,0543	0,0234

IOP(m-^{1})		620		660		680		710	
		In Situ	MERIS	*In Situ*	MERIS	*In Situ*	MERIS	*In Situ*	MERIS
	min	0,0032	0,0069	0,0028	0,0060	0,0027	0,0057	0,0024	0,0052
	max	0,1821	0,4286	0,1767	0,3981	0,1742	0,3843	0,1706	0,3652
bbp	mean	0,0366	0,0649	0,0345	0,0599	0,0336	0,0576	0,0323	0,0545
	min	0,0673	0,0851	0,0439	0,0783	0,0374	0,0790	0,0250	0,0598
	max	0,2762	0,1502	0,2617	0,1651	0,2657	0,1731	0,2740	0,1892
a	mean	0,1497	0,1180	0,1305	0,1181	0,1217	0,1220	0,1040	0,1118
	min	-0,0034	0,0013	-0,0019	0,0007	-0,0014	0,0005	-0,0009	0,0003
	max	0,0228	0,0073	0,0125	0,0040	0,0093	0,0030	0,0059	0,0019
adg	mean	0,0026	0,0034	0,0014	0,0019	0,0011	0,0014	0,0007	0,0009
	min	-0,2082	-0,1923	-0,3661	-0,3327	-0,4276	-0,3867	-0,8020	-0,7676
	max	-0,0219	-0,1297	-0,1607	-0,2474	-0,2086	-0,2937	-0,5590	-0,6390
aph	mean	-0,1298	-0,1609	-0,2831	-0,2937	-0,3466	-0,3443	-0,7257	-0,7161

The total absorption coefficient (a) of the Berau estuary waters from previous study (Ambarwulan *et al.*, 2011) found the absorptiom of chlorophyll-a (Chl-a) was between 0,037 to 0,108 (m^{-1}). The a_{ph} was higher in short wavelength decreased with increasing wavelength. In other hand, the absorption coefficient of the combined absorption of colored detritus and dissolved material, a_{dg} derived from R_{rs} *in situ* measurement was lower compared to the R_{rs} MERIS derived data. The a_{ph} decrease with increasing wavelength and started at wavelength 620 nm were negative value.

In order to understand between both data sets, the coefficient of determination (R^2) and root mean square error (RMSE) were calculated and were displayed in Table 2. The RMSE was used to express the differences between IOPs of R_{rs} measured and R_{rs} derived from MERIS data. The R^2 of b_{bp} was the highest compare to the total absorption (a) as well as a_{dg} and a_{ph}. The R^2 of the b_{bp} increased with increasing wavelengths. The RMSE of the b_{bp} was also the lowest one compare to the others and decrease the RMSE with increasing the wavelength.This can be explained due to the backscattering of particle more sensitive in the high wavelength. However the R^2 of total absorption coefficient (a) decrease with increasing wavelength. The magnitude of RSME of a was decreased with increasing the wavelength. In this study the a_{dg} on all wavelengths were similar (R^2=0,35), however the RMSE decreased with increasing the wavelength. The absorptionof Phytoplankton (a_{ph}) has similar trend with b_{bp} which is decreased with increasing wavelength. This result can be explained due to the absorption is more sensitive in the short wavelength (blue and green band).

3.2 Retrieving IOPs using C2R

The Case 2 Regional algorithm developed by Doeffer (2007) plug-in on the Beam Visat derived some parameters of the water body such as IOPs (a_{dg}, TSM concentration, Chlorophyll_a concentration and AOP reflectance). The distribution of IOPs of the Berau estuary derived from MERIS data using C2R processor algorithm is displayed in Figure 2. It clearly shows that the study area, which is located in a tropical region, was usually covered by clouds. It was difficult to find MERIS data with low cloud cover, as shown clearly in Figures 2. High IOPs were found at the location close to the river mouth and they decrease when going into the outer shelve.

Table 2. Inter-comparison between IOPs of R_{rs} derived from *in situ* measurement and R_{rs} of MERIS after MODTRAN Atmospheric correction.

Wavelength (nm)	R^2				RMSE			
	b_{bp}	a	a_{dg}	a_{ph}	b_{bp}	a	a_{dg}	a_{ph}
410	0,73	0,58	0,35	0,66	0,0675	0,0765	0,0814	0,0719
440	0,74	0,67	0,35	0,66	0,0615	0,0926	0,0519	0,0963
490	0,76	0,81	0,35	0,79	0,0534	0,0948	0,0245	0,0905
510	0,76	0,82	0,35	0,81	0,0506	0,0774	0,0182	0,0752
560	0,78	0,85	0,35	0,83	0,0446	0,0365	0,0086	0,0349
620	0,79	0,32	0,35	0,27	0,0389	0,0434	0,0035	0,0414
660	0,80	0,03	0,35	0,02	0,0357	0,0529	0,0019	0,0499
680	0,80	0,04	0,35	0,03	0,0342	0,0544	0,0014	0,0517
710	0,81	0,003	0,35	0,001	0,0322	0,0575	0,0009	0,0571

The inter-comparison between IOPs derived using QAA and using C2R of MERIS data August 31, 2007 displays in Figure 3. The results showed a large discrepancy between the backsacttering coeffcient of particles (b_{bp}) at wavelength 440 nm derived from MERIS data using C2R and QAA, indicating by a relatively low correlation (R^2=0.57) and the relatively high RMSE (RMSE=0.891). The insufficient atmospheric correction achieved in the C2R processor algorithms and MODTRAN at the blue wavelength domain may be responsible for this.

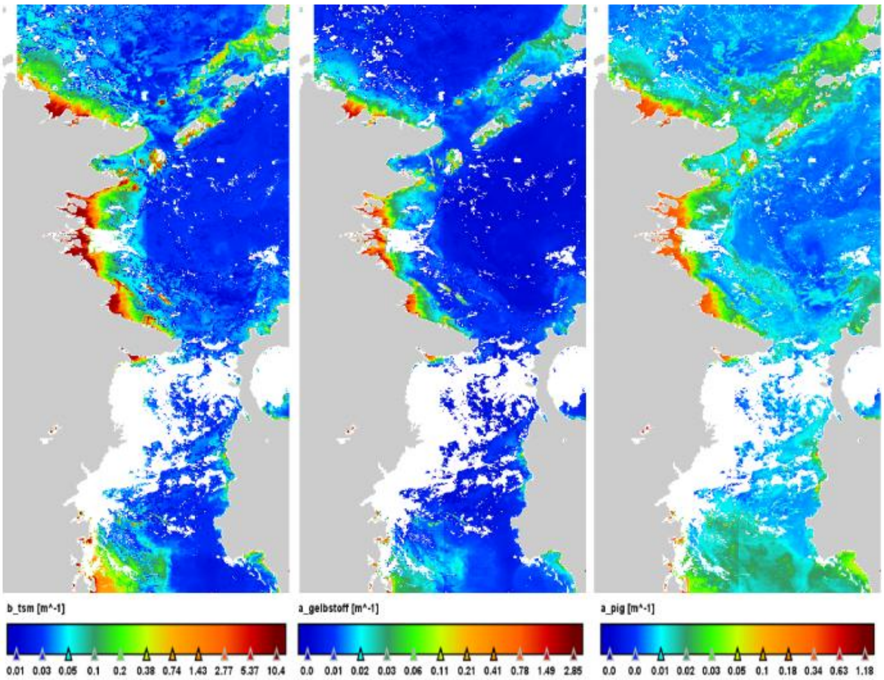

Figure 2. IOPs of the Berau Estuary waters derived from MERIS RR (August 31, 2007) using C2R algorithm.

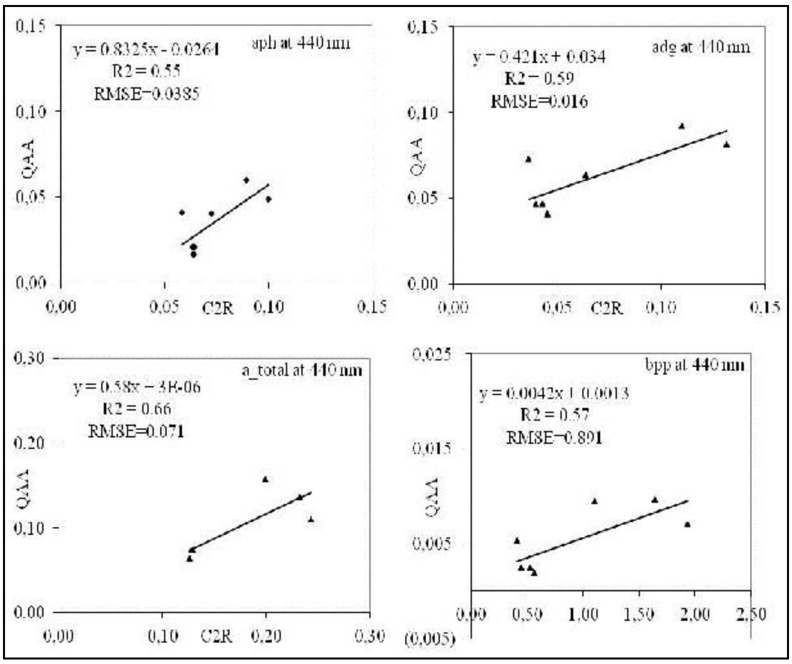

Figure 3. The inter-comparison between IOPs derived from MERIS RR (August 31, 2007) data using QAA and using C2R.

In the case of absorption, the total absorption (*a*) showed a relatively better correlation between both algorithms (R^2=0,66). However, the decomposition of *a* intio a_{dg} and a_{ph} at the same wavelength produced relatively low correlation (R^2=0.59). The descrepancy between both algorithm could be explained by three reasons (Ambarwulan, *et al*., 2010): (i) large error induced by atmospheric correction in cloud-shadowed (Matthew *et al.*, 2000) and hazy regions which prevailed off shore the Berau estuary; (ii) large error induced by model parameterization and inversion in turbid waters; and (iii) large error induced by model parameterization and inversion in clear area affected by bottom reflectance.

4 CONCLUSION

In the equatorial coastal zone, the MERIS RR data permitted to derive inherent optical properties (IOPs) with a reasonable accuracy. The QAA proved robust for estimation IOPs from *in situ* measurement and MERIS data. The inter-comparison between IOPs retrieved from R_{rs} *in situ* measurement and R_{rs} MERIS data found that the backscattering coefficient (b_{bp}) was the best correlation (R^2>73) compare to the absorption coefficient (a, a_{dg}, a_{ph}). This study also evaluated the IOPs derived from MERIS data using QAA algorithm and C2R processor algorithm. The inter-comparison of IOPs (b_{bp}, a, a_{dg} and a_{ph}) on wavelength 440 nm found that the absortion coefficient, *a*, was the highest R^2 compare to others. However in term of RMSE, the b_{bp} was the highest RMSE value the compare to the RMSE of absorption coefficient.

ACKNOWLEDGMENT

The financial support for this research was provided under the East Kalimantan Project financed by the Foundation for the Advancement of Tropical Research (WOTRO) – Royal Netherlands Academy of Arts and Sciences (KNAW). The authors would like to thank the European Space Agency for providing the MERIS data. Acknowledgement also to Prof. Dr Ing Wouter Verhoef, Dr C.M. Mannaerts, Dr. M.S. Salama, and Dr. H.J. van der Woerd for the invaluable advice and assistance.

REFERENCES

Ambarwulan, W., M.S. Salama, C.M. Mannaerts, W. Verhoef, 2011, Estimating the specific inherent optical properties of tropical coastal water using bio-optical model inversion in the Berau Coastal Waters, Indonesia. *Hydrobiology Journal*, 658:197–211 DOI 10.1007/s10750-010-0473-7.

Ambarwulan, W., 2010, Remote sensing of tropical coastal waters: case study of the Berau Estuary - East Kalimantan, Indonesia. PhD Dissertation. University of Twente - International Institute for Geo-information Science and Earth Observation, Enschede, The Netherlands. 153p. Berk, A., G.P. Anderson, P.K. Acharya, J.H. Chetwynd, L.S. Bernstein, E.P. Shettle, M.W. Matthew, and S.M. Adler-Golden, 2000, MODTRAN4 USER's MANUAL. Hanscom AFB: Air Force Research Laboratory, Space Vehicles Directorate, Air Force Materiel Command, MA 01731–3010, 97p.

Bhatti, A.M., D. Rundquist, J. Schalles, L. Ramirez, and S. Nasu, 2009, A comparison between above-water surface and subsurface spectral reflectances collected over inland waters. *Geocarto Int.*, 24:133–141.

Doerffer, R. H. Schiller, 2007, The MERIS case 2 water algorithm. *Int. J. Remote Sens.*, 28:517–535.

Gege, P., 2005, The water colour simulator WASI, User manual for Version 3. DLR Internal Report IB 564-01/05. 83p.

Gordon, H.R. and A.Y. Morel, 1983, Remote assessment of ocean color for interpretation of satellite visible imagery: a review. Springer Press, New York.

IOCCG, 2006, Remote sensing of inherent optical properties: fundamentals, tests of algorithms, and applications. Lee, Z.P. (ed.), *Reports of the International Ocean-Colour Coordinating Group, No. 5, IOCCG*, Dartmouth, Canada.

Lee, Z.P., R. Arnone, C. Hu, P. J. Werdell, B.Lubac, 2010, Uncertainties of optical parameters and their propagations in an analytical ocean color inversion algorithm, *Appl. Opt.*(49) No. 3, 369-481.

Lee, Z.P., K.L. Carder, and R. Arnone, 2002, Deriving inherent optical properties from water color: a multiband quasi-analytical algorithm for optically deep waters, *Appl. Opt*., 41:5755–5772.

Matthew, M.W., S.M. Adler-Golden, A. Berk, S.C. Richtsmeier, R.Y. Levine, L.S. Bernstein, P.K. Acharya, G.P. Anderson, G.W. Felde, M.P. Hoke, A. Ratkowski, H-H. Burke, R.D. Kaiser, D. P. Miller, 2000, Status of atmospheric correction using a MODTRAN4-based algorithm. SPIE Proceeding, Algorithms for Multispectral, Hyperspectral, and Ultraspectral Imagery VI, Volume 4049.

Mobley, C.D., 1994, Light and water - radiative transfer in natural waters. Academic Press, San Diego.

Nelson, N.B. and D.A. Siegel, 2002, Chromophoric DOM in the open ocean. *In*: Biogeochemistry of marine dissolved organic matter. Hansell, D.A., and Carlson, C.A. (eds), Academic Press, San Diego, 774p.

Nelson, N.B., D.A. Siegel, and A.F. Michaels, 1998, Seasonal dynamics of colored dissolved material in the Sargasso Sea. *Deep-Sea Res*., 45:931-957.

Preisendorfer, R.W., 1976, Hydrologic optics. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Research Laboratories, Pacific Marine Environmental Laboratory.

Salama, M.S., A. Dekker, Z. Su, C.M. Mannaerts, and W. Verhoef, 2009, Deriving inherent optical properties and associated inversion-uncertainties in the Dutch Lakes, *Hydrology and Earth System Sciences*, 13:1113-1121.

Schroeder, T. and M. Schaale, 2005, MERIS Case-2 water properties processor, version 1.0.1, Institute for Space Sciences, Freie Universität Berlin (FUB) http://www.brockmann-consult.de/beam/software/plugins/FUB-WeW-Water-1.0.1.zip (accessed on June 29, 2007).