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

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ABSTRACT

The paper describes Inherent Optical Properties (IOP) of the Berau coastal waters derived from *in situ* measurements and Medium Resolution Imaging Spectrometer (MERIS). 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 period, only four MERIS data were coincident with *in situ* measurements: August 31, 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), 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

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 40 to 100 km from the mouth of the Berau river. Water quality monitoring in this environment becomes increasingly important, because enhanced anthropogenic activities in the Berau catchment, such as coal mining and deforestation, have 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 such MPA.

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 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). The IOPs such as the scattering and absorption characteristics of water and its constituents (the dissolved and suspended material). Variations in IOPs are clear indications of changes in water mass or water constituents. 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 $R(O)$, remote sensing reflectance (R_{rs}). Various models have been developed to

relate IOPs to 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 is 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 is to calculate optical properties in a level-by-level scheme. Firstly, the values of total absorption and backscattering coefficients are analytically calculated from values of remote-sensing reflectance. Then, phytoplankton and CDOM coefficients are decomposed from the total absorption coefficients. The goal of this research is retrieving IOPs from MERIS data using QAA and Case-2 Regional Algorithm.

MATERIALS AND METHODS

The Study Area

The area of present study is Berau Estuary waters, situated in the Makassar straits which is the Indonesian Through-Flow (ITF) which passes in the strait (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 is 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.

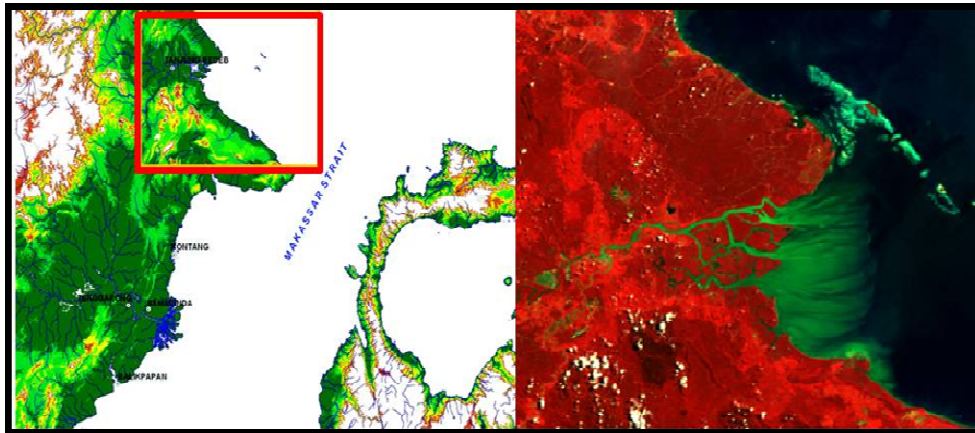


Figure 1. The Berau Estuary, East Kalimantan, Indonesia

In situ observations

The *in situ* observations from the area of study involve water sampling, in-water radiometer measurements (using Ocean Optic Spectrometer - USB4000), Secchi disk depth measurement for transparency of light and bio-geophysical parameters measured using a Horiba U10 water quality multi-sensor probe, are conductivity, 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 from the area where the shadow of the boat did not fall.

The apparent optical properties (AOP) generated through water sample analysis

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

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) are 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 for atmospheric simulation and correction have been applied in this study was MODerate spectral resolution atmospheric TRANsmittance (MODTRAN) (Berk *et al.*, 2000). The Case-2 Regional algorithm processor (C2R) (Doerffer & Schiller, 2007) and the Free University of Berlin algorithm processor (FUB) (Schroeder & Schaale 2005) are Case-2 plug-in algorithms in BEAM Visat, and they are based on an Artificial Neural Network trained on the basis of radiative transfer model calculations. The main task of these algorithms is to retrieve the Top-of-water (TOW) reflectance from the Top-of-atmosphere (TOA) reflectance that is derived from the radiance measured by the sensor.

Deriving Inherent Optical Properties from Model Inversion

The IOPs of Berau estuary waters have 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 is 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 ($a(\lambda)$) is 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 ($b_b(\lambda)$) is partitioned into terms due to seawater, $b_{bw}(\lambda)$, and suspended particulates, $b_{bp}(\lambda)$. The retrieved IOPs using QAA include $a(\lambda)$, $b_{bp}(\lambda)$, $a_{ph}(\lambda)$, and $a_{dg}(\lambda)$ of wavelengths r_{rs} values at 410, 440, 490, 510, 555, and 670 nm.

RESULTS AND DISCUSSION

Retrieving IOPs using QAA

The QAA algorithms steps to retrieve IOPs from R_{rs} are 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 is 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 ($b_{bp}=0,019 - 0,604 \text{ m}^{-1}$).

Table 1, the backscattering coefficients of suspended particles b_{bp} of R_{rs} of *in situ* measurement and R_{rs} MERIS data shows the highest value of the b_{bp} was obtained in the short wavelength and continually decreases with increasing wavelength. 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 can 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 km² water surface area (1.2 km resolution RR data).

The total absorption coefficient (a) of the Berau estuary waters from previous study (Ambarwulan *et al.*, 2011) found the absorption of Chlorophyll (a_{Chl}) was between 0,037 to 0,108(m^{-1}). The a_{ph} is 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 a derived from R_{rs} MERIS data. The a_{ph} decrease with increasing wavelength and started at wavelength 620 nm were negative value.

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	
		<i>In Situ</i>	MERIS	<i>In Situ</i>	MERIS	<i>In Situ</i>	MERIS	<i>In Situ</i>	MERIS	<i>In Situ</i>	MERIS
<i>b_{bp}</i>	min	0,0078	0,0161	0,0067	0,0139	0,0053	0,0112	0,0049	0,0103	0,0040	0,0085
	max	0,2219	0,6986	0,2145	0,6427	0,2037	0,5659	0,1999	0,5398	0,1911	0,4834
	average	0,0549	0,1111	0,0511	0,1013	0,0459	0,0880	0,0441	0,0836	0,0403	0,0740
<i>a</i>	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
	average	0,1582	0,1053	0,1696	0,0857	0,1767	0,0970	0,1604	0,0914	0,1239	0,0936
<i>ad_g</i>	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
	average	0,0608	0,0794	0,0388	0,0506	0,0183	0,0239	0,0136	0,0177	0,0064	0,0084
<i>a_{ph}</i>	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
	average	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	
		<i>In Situ</i>	MERIS	<i>In Situ</i>	MERIS	<i>In Situ</i>	MERIS	<i>In Situ</i>	MERIS
<i>b_{bp}</i>	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
	average	0,0366	0,0649	0,0345	0,0599	0,0336	0,0576	0,0323	0,0545
<i>a</i>	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
	average	0,1497	0,1180	0,1305	0,1181	0,1217	0,1220	0,1040	0,1118
<i>ad_g</i>	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
	average	0,0026	0,0034	0,0014	0,0019	0,0011	0,0014	0,0007	0,0009
<i>a_{ph}</i>	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
	average	-0,1298	-0,1609	-0,2831	-0,2937	-0,3466	-0,3443	-0,7257	-0,7161

In order to understand between both data sets, the coefficient of determination (R^2) and Root Mean Square Error (RMSE) were calculated and are 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 absorption of 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).

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			
	<i>b_{bp}</i>	<i>a</i>	<i>a_{dg}</i>	<i>a_{ph}</i>	<i>b_{bp}</i>	<i>a</i>	<i>a_{dg}</i>	<i>a_{ph}</i>
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

Retrieving IOPs using C2R

The Case 2 Regional algorithm developed by Doeffler (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 shelf.

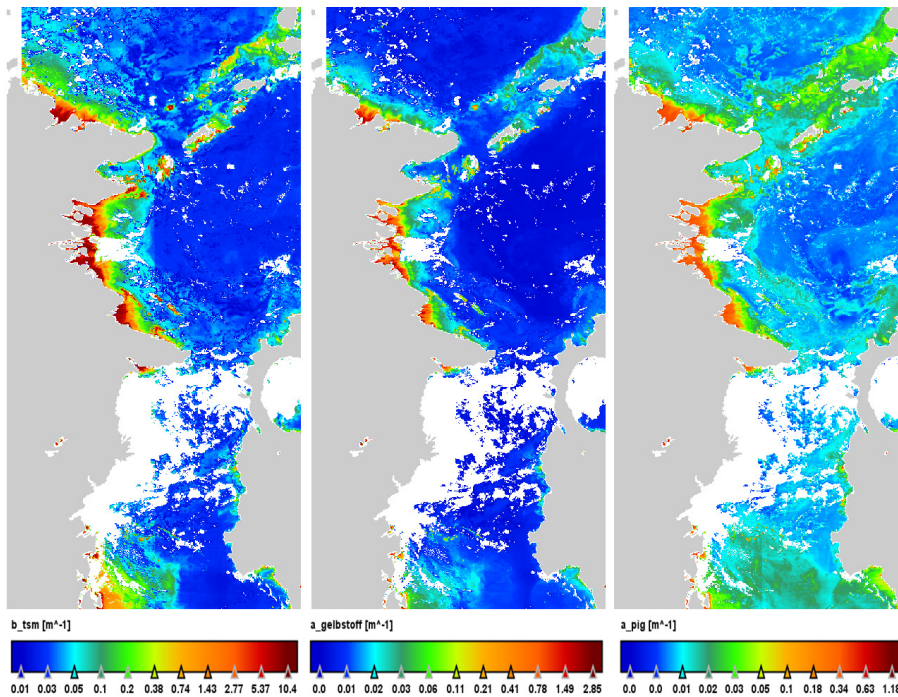


Figure 2. IOPs of the Berau Estuary waters derived from MERIS RR (August 31, 2007) using C2R algorithm

The inter-comparison between IOPs derived using QAA and using C2R of MERIS data August 31, 2007 displays in Figure 3. The results shows a large discrepancy between the backsacttering coefficient of particles (*b_{bp}*) at wavelength 440 nm derived from MERIS data using C2R and QAA, indicated by a not good enough the correlation squared (R²) and the RMSE. Th insufficient atmospheric correction achieved in the C2R processor algorithms and MODTRAN at the blue wavelength domain may be responsible for this.

In the case of absorption, the total absorption (*a*) shows a good correlation between both

algorithms ($R^2=0,66$). However, the decomposition of a into a_{dg} and a_{ph} at the same wavelength showed not good correlation. The discrepancy 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.

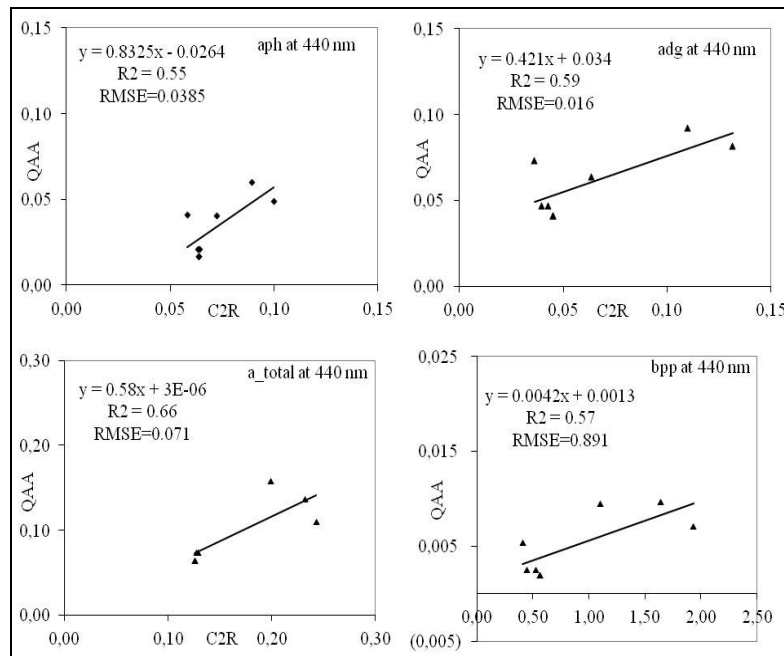


Figure 3. The inter-comparison between IOPs derived from MRTIS RR (August 31, 2007) data using QAA and using C2R

CONCLUSION

From the results obtained, it can be concluded that in this equatorial coastal zone, the MERIS RR data permit 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 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 the absorption coefficient, a , was the highest R^2 compare to others. However in term of RMSE, the b_{bp} was the highest RMSE value compare to the RMSE of absorption coefficient.

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