WATER QUALITY ASSESSMENT IN THE NHA TRANG BAY (VIETNAM) BY USING IN-SITU AND REMOTELY SENSED DATA

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Abstract

The Nha Trang Bay (Vietnam) is an international marine protected area with significant economic, natural and recreational values. Considerable economic development is expected in particularly for tourism, navigation and aquaculture. However, in recent years the environmental quality of the Bay has been degraded by human activities and impacts. Even though the conditions of the Bay are monitored with in-situ measurements in a marine station, the environmental data, measured only in half-yearly intervals, are not sufficient for comprehensively assessing environmental quality at various temporal and spatial scales. Therefore, it is necessary to seek for complementary data sources to assess, control and manage the marine environment of Nha Trang Bay.

We conducted three field trips in Nha Trang Bay at 23 stations, including 6 off-shore stations that are not influenced by freshwater from land, and measured the distribution of marine optical properties. These properties include the light extinction coefficient (K) of photosynthetically active radiation (PAR) in the surface layer (i.e. 1m depth) and in water columns. K ranged from 0.099 m^{-1} off-shore to 0.409 m^{-1} in coastal waters. In addition, light absorption at various wavelengths were used to assess the concentration of chlorophyll-a, total suspended sediments and primary production. Further, we collected and used spatially explicit data using the OC4 method and the method of band 1, 2 and 3 ratios of the Landsat TM satellite. A data comparison confirms a significant correlation between the different sources of in-situ and remotely sensed data of light absorption. However, the predicted values at stations with a water depth of less than 5 m are significantly affected by sea bottom reflection of, for example, mud, sand, coral reefs and algae.

The results indicate that it is appropriate to use remote sensing methods to derive spatially explicit distributed variables of optical properties and derived products for an environmental assessment of coastal waters.

1. INTRODUCTION

The coastal zone of Nha Trang was oriented towards sustainable development of marine resources including economics, eco-tourism, aquaculture and marine transportation. Nha Trang Bay is located in center of Vietnam and it includes an important international marine protected area since 2001. Due to pressures of economic development, human living activities and natural changes, marine environmental have degraded significantly both in water and in soil quality. Thus, a national monitoring station that collected data with frequency of every 2-4 times per year, was established in 1996. The monitoring results indicated that the concentration of several environmental factors increased. Some of them faced the limitation of Vietnamese environmental standard, such as bacteria, organic mater, total suspended sediment (TSS), nutrients and heavy metals. However, this evidence did not show the general view of marine environment in Nha Trang Bay.

Applying remote sensing for water quality assessment has proved satisfactorily on national and regional level. Specifically environmental factors that interacted with energy of solar light in coastal regions can be assessed (reviewed by Green et al., 2000; Miller et al., 2005). In Vietnam, remote sensing methods have been applied for chlorophyll-a (Chl-a), TSS and primary production (PP) (e.g. Nguyen Tac An et al., 2003; Tong Phuoc Hoang Son and Nguyen Tac An, 2005) but there are not any results, which clearly demonstrated the relationship between in-situ data and remote sensing prediction, specifically for high resolution images.

This paper aims to use the marine optics and develops estimation approaches of environmental factors from light interaction.

2. MATERIALS AND METHODOLOGIES

The study was carried out at twenty three stations in the Nha Trang Bay. Nineteen stations were sampled in April 2007, eight stations in June 2007 and all twenty three stations again in April 2008 (Fig. 1). Six stations had a water depth less than 5m (the so-called shallow stations). Stations in Area A are affected by fresh water (the so-called coastal stations) and all others were off-shore stations. Station 1 (sampled in April 2007 and 2008) is located in *Sargassum* beds and reefs.

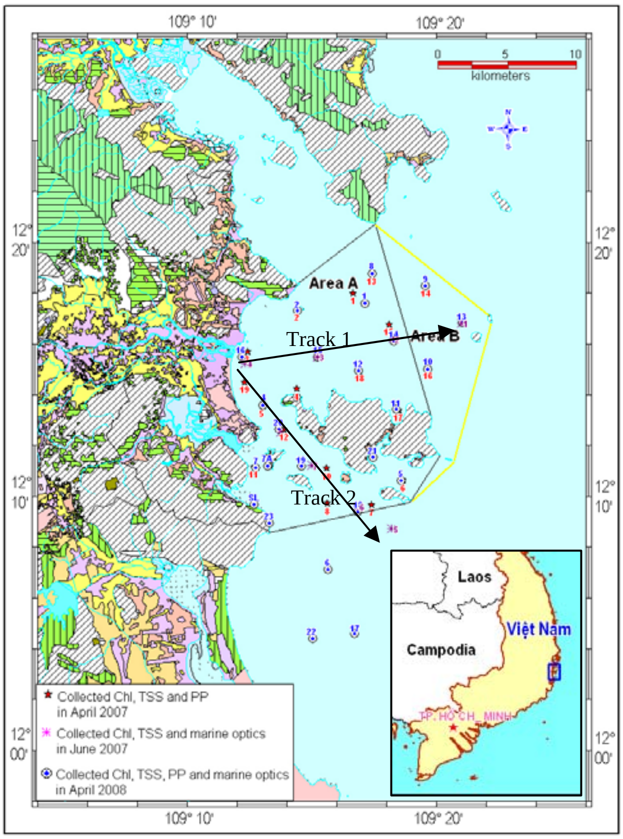

Figure 1: Map of study stations.

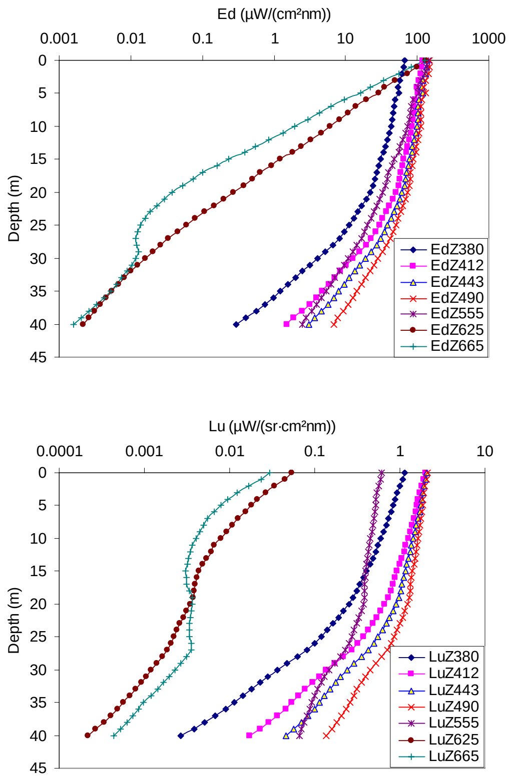

Figure 2: Profiles of Ed (above) and Lu (below) at station 10 in April 2008

The water samples were collected at layers of 0m, 5m, 10m, 20m and 30m in 5 litter plastic cans, which were kept dark when transferred to the laboratory. Water samples for Chl-a and TSS were filtered as soon as possible. Marine optics were identified by PRR 2600 (High-Resolution Profiling Reflectance Radiometer) at eight reflectance wavebands of respectively 380, 412, 443, 490, 555, 625, 665 nm with the value of downwelling irradiance (Ed(z)) and upwelling radiance (Lu(z)), and PAR (photosynthetically active radiation).

Several measuring were sampled. Chl-a is extracted in 90% acetone at 0°C for 24h and measured by the 10-AU Fluorometer. TSS is weighed after drying at 105°C for 24h. Primary production is used the in-situ dark and light bottle method for 24h. Estimation of Chl-a and TSS from light absorption based on the OC4 method (equation 1) and Kishino's approach (equation 2) (Cited in Siripong and Matsumura, 2005), respectively:

$$Chla(ug/L) = 10^{0.531-3.559R+4.488^2-2.169R^3} - 0.23 \qquad (1)$$

With $R = Log_{10}((R_{RS}(443) > R_{RS}(460) > R_{RS}(520))/R_{RS}545)$

$$TSS = 10^{-0.3186-1.5935R+0.4376R^2} \quad \text{with } R = Log_{10}(R_{RS}(443)/R_{RS}(545)) \qquad (2)$$

$$K_{PAR}(z) = \frac{\ln Ed_{PAR}(z+1) - \ln Ed_{PAR}(z-1)}{(z-1)-(z+1)} \qquad (3)$$

in which $K_{PAR}(z)$: the vertical light extinction coefficient of PAR at z depth; and $Ed_{PAR}(z)$: Downwelling Irradiance of PAR at z (m) depth.

PP was estimated by a vertically generalized production model in Behrenfeld et al. (1997) and corrected by modeling in Platt and Sathyendranath (2002).

In addition, it is assumed that the PRR values at 490nm, 555nm and 665nm are presented DI of band 1 (450-520nm), band 2 (530-610nm) and band 3 (630-690nm) of Landsat ETM images, respectively. Then, we would like to find the relationship between in-situ Chl-a and TSS with the band value. The results would be helped to estimate and predict the environmental factors from remote sensing images. Generally, data of three cruises shown in Table 1 and an example of Ed and Lu profile indicated in Figure 2.

Table 1: Chl-a, TSS and PP in study areas

Time	Chl-a ($mg.m^{-3}$)	TSS ($g.m^{-3}$)	TOM ($g.m^{-3}$)	PP ($mgC.m^{-3}.day^{-1}$)
April 2007	0.089 - 0.598 0.265 ± 0.123	0.20 - 1.65 0.73 ± 0.41	0.15 - 1.15 0.57 ± 0.26	3.75 - 266.25 77.84 ± 71.25
June 2007	0.085 - 10.700 3.664 ± 2.391	0.27 - 15.07 2.58 ± 2.78	0.200 - 13.87 1.04 ± 2.40	
April 2008	0.164 - 1.320 0.498 ± 0.287	0.33 - 10.73 2.26 ± 1.91	0.11 - 2.13 0.56 ± 0.40	7.50 - 286.88 68.32 ± 62.19

Noted: (Min – Max)/(average ± SD)

3. RESULTS AND DISCUSSIONS

3.1. K_{PAR}

The $K_{PAR}(1)$ in Nha trang Bay in June 2007 and April 2008 ranked 0.137 – 0.319 and

0.099 – 0.409 m^{-1}, respectively. The highest value was found at Cai Mouth in April 2008. Runoff from Cai River impacted changes of K_{PAR} in around Cai mouth – station 16 in April 2008 (Fig. 3b and 3c) and station 4 in June 2007. However, because the runoff is low in dry season, the sphere of influence from fresh water located in eastern and southern areas of Cai mouth with radius of 4-5 km.

Generally, the K_{PAR} in water column in Nha Trang was from 0.06 to 0.20 m^{-1} (Fig. 3a). At some stations, K_{PAR} was high due to increasing concentration of phytoplankton and TSS which were brought from runoff water of Cai River (station 16 in April 2008) aquaculture (stations 7A, 18 and 21 – April 2008), human live (station 4 – April 2008) and port activities (Station 20 – April 2008) (Fig 3b and c). In addition, some stations located at coral reefs and algae beds had high K_{PAR} value due to releasing Sargassum spore (for example, station 1).

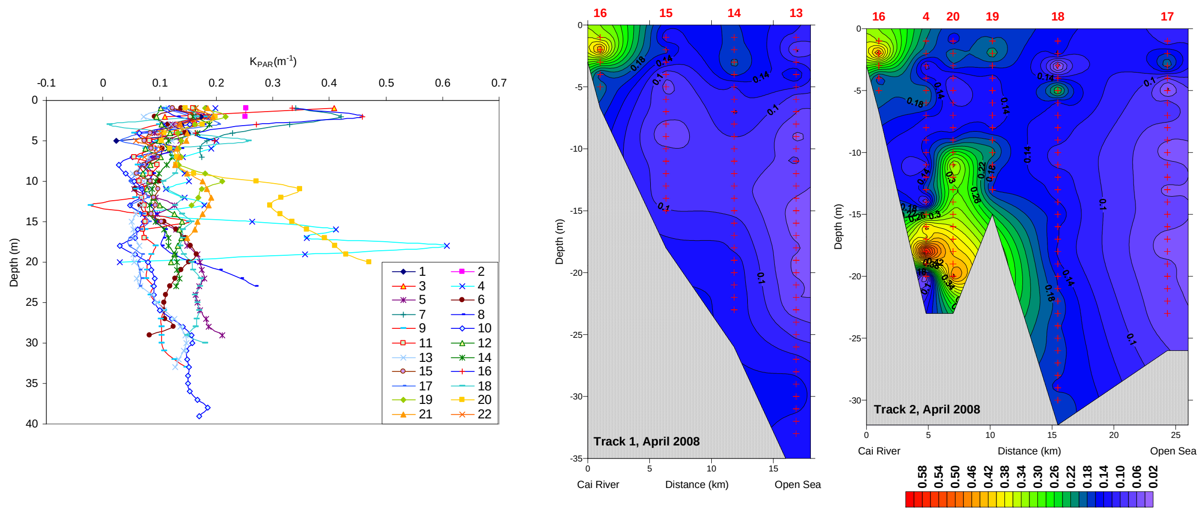

Figure 3: Profile of K_{PAR} in Nha Trang Bay in April 2008 (left - a) and distribution of K_{PAR} in transect 1 (middle- b) and transect 2 (right -c).

3.2. Chl-a and TSS: in-situ data vs. remote sensing estimation

Based on distribution of in-situ chl-a and TSS in the cruises of April 2007 and 2008, Nha Trang bay could be divided into 2 parts, northern part affected strongly freshwater in rainy season and southern influenced more ocean. However, we targeted to the relationship between in-situ data and remote sensing data (estimated from light absorption). The results (Figs. 4 and 5) indicated that if the whole data sets were tested the Chl-a and TSS estimation, there were the week relationship between in-situ data and predicted data (Fig. 4a and 5a). However, when the data at the shallow stations (having water depth less than 5m) and specific stations (having macro-algae and coral reefs) were taken off, a significant relationship was established (Fig. 4b and 5b). Nevertheless, the predicted values were less 8 (for chl-a) and 14 (for TSS) times than in-situ data.

There were different phenomenon of the Chl-a and TSS relationship between measured data and estimation from light absorption. When only four values of TSS at the shallow stations were removed, the correlation of in-situ and predicted data was significant (Fig.5). On the other hand, the relationship of Chl-a was only established as more data (nine values) were removed from the shallow stations and stations having macro-algae or coral reefs (Fig. 4). This demonstrates the importance of reflectance of light from bottom ground at shallow stations and the effects of organic matters and pigments of macro-algae and coral reefs.

However, these relationships also show that the value at 490nm and 555 nm could be applied for recognizing Chl-a and TSS in the Case II waters.

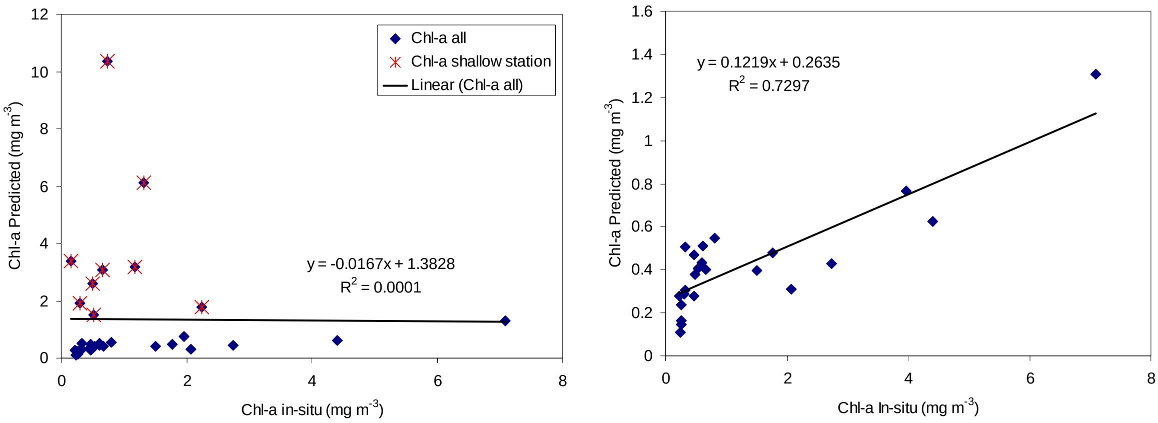

Figure 4: Relationship of Chl-a between in-situ data with estimation value from light absorption (a - left) week relationship with all data (b - right) significant relationship when data at shallow and specific stations were removed

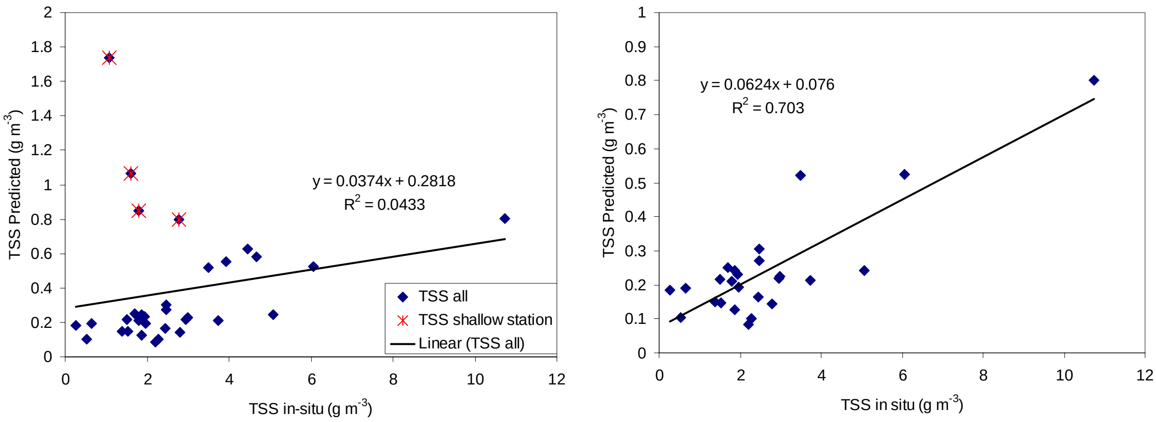

Figure 5: Relationship of TSS between in-situ data with estimation value from light absorption (a - left) week relationship with all data (b - right) significant relationship when data at shallow stations were removed.

Therefore, these relationships between in-situ data of Chl-a and TSS with DI value of LandSat images (converted from light absorption) at band 1, 2 and 3 was also tested. Results indicated that Chl-a had a significant nonlinear relationship with B1 and B2 (equation 5) and a linear relationship with ratio of B1 and B3 (equation 6), while TSS was considerable linear correlation with B2 (equation 7).

$$Ln(Chl) = -4.254\,Ln(B1) - 1.626Ln(B2) - 11.825 \quad n=24 \quad R^2 = 0.629 \quad Sign.=0.000 \quad (5)$$

$$Ln(Chl) = 17.033\,Ln(B1)/Ln(B3) - 10.410 \quad n=24 \quad R^2 = 0.475 \quad Sign.=0.000 \quad (6)$$

$$Ln(TSS) = -3.796\,Ln(B2) + 23.354 \quad n=28 \quad R^2 = 0.433 \quad Sign.= 0.000 \quad (7)$$

3.3. Primary production

PP in the Nha Trang Bay varied significantly both in vertical and horizontal distribution (Table 1 and Fig. 6). In the whole water column, the distribution has a uniform shape. Thus, we can estimate the PP using the vertically generalized production model by Platt and Sathyendranath (2002) if the eutrophic depth is more than water depth.

Estimation of PP base on modeling of this model with P^B_{opt} = 8.13 mgC (mg Chl)$^{-1}$ h^{-1} (Table 2) indicated that there was not significantly deferent between PP1 and PP2.

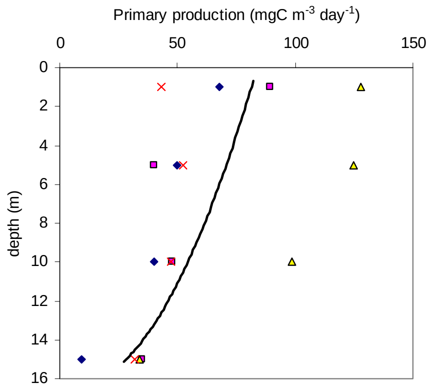

Fig. 6: A distribution uniform of PP in Nha Trang Bay

Table 2: Estimation of PP (mgC m^{-2} day^{-1}) from in-situ Chl-a (mg m^{-3}) (PP1) and predicted Chl-a from equation (5) (PP2)

Factor	Min	Max	Average±SD
In-situ Chla	0.164	1.172	0.461±0.235
PP1	72.75	1225	662.4±301.8
Pre. Chla	0.144	1.465	0.485±0.364
PP2	332.8	1359	724.7±297.5

4. CONCLUSIONS

Although the estimation results from light absorption were contributed by light refraction of sea ground features, such as sand, muddy, macro algae and reefs, the paper shows the potential application of high resolution images for water quality assessment, with case study in Nha Trang Bay.

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