Study on variation in turbidity in Cam Ranh Bay and Thuy Trieu Lagoon, Vietnam

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1. Introduction

1.1 Background

Turbidity is an important water quality parameter and an indicator of water pollution (Güttler et al., 2013). This parameter determines to what extent the material in water decreases the passage of light through the water column (Zhen, 2007) and closely related to water clarity. Turbidity can harm fish and other aquatic life by reducing food supplies, degrading spawning beds, and affecting gill function (Minnesota Pollution Control Agency, 2008). In estuarine or lagoon where turbidity is usually very high, the concentration of dissolved oxygen can dramatically decrease as a result of negative balance between autotrophic and heterotrophic biological processes, thus negatively affecting marine organisms (Gernez et al., 2014). Variations in turbidity also influence the physiological responses of suspension-feeders such as oysters, mussels and others like seaweeds, lobster that are farming in Cam Ranh Bay (Gernez et al., 2014).

Traditionally, turbidity is often estimated visually using a Secchi disk or measured directly with nephelometry (Zhen, 2007; Carson et al., 2015). In recent years, ocean color remote sensing has been shown to be a useful tool to map turbidity and suspended particulate matter concentration in turbid coastal waters (Dogliotti et al., 2015). The strength remote sensing for water resources management is its ability to capture synoptic data of a whole study area to produce continuous surfaces of data, often showing detailed spatial variability in water quality (Allan et al., 2011). Many remote sensing studies have been devoted to retrieve TSS, the parameter of main interest in sediment transport studies, but less to retrieve turbidity (Dogliotti et al., 2015). However, turbidity is one of the most important effective indicators of water quality and closely related to TSS. In this study, the spatiotemporal variation of turbidity using remotely sensing data combined *in situ* measurements was investigated.

1.2 Motivations and purposes of the study

The limitations in both spatial and temporal water management in Cam Ranh Bay and Thuy Trieu Lagoon are resulting in water quality degraded. It is important to have long-term water quality information on a broad spatiotemporal scale for effective environmental planning and management. This study will be very useful and promising for local policy marker in decision making because the spatiotemporal information of water quality will be supplied frequently. Therefore, development the algorithm for determining spatiotemporal distribution of turbidity is urgent need to obtain sustainable water management in the study area.

The main goal of this study is to determine the variation as well as major factors affecting the spatiotemporal patterns of turbidity in Cam Ranh Bay and Thuy Trieu Lagoon. To achieve this, the following specific objectives must be satisfied: (i) to develop new algorithm for the accurate estimation of turbidity using Landsat 8 OLI combined field measurements; (ii) to understand the spatial and temporal variations, and; (iii) To elucidate the processes and factors controlling the spatiotemporal pattern of turbidity.

2. Materials and methods

2.1 Study site

Cam Ranh Bay and Thuy Trieu Lagoon located in the Southeast of Vietnam (11°49'0.41"N to 12° 6'58.64"N, 109° 7'22.78"E to 109°12'54.61"E) is one of the most famous naturally depth bays in the world. This is a slightly closed water area, with an average depth of 10 m and 35 km in length. The entire area reaches 119 km^2 of water surface (Fig. 1). During the dry season, the air temperature increases from 24.5°C in January and reaches maximum around 29°C in May. It remains stable to August, end of dry season and gradually decreases to 24.5°C in December, end of rainy season. Besides, the study area is situated in a monsoon trophic region, wind directions change seasonally. In overall, the Bay and Lagoon are protected inside from the open sea by the Cam Ranh peninsula, which extends downward from the North.

2.2 Materials

Totally, eighteen Landsat 8 OLI images with lowest cloud cover, no rain and high visibility, suitable conditions covering whole Cam Ranh Bay and Thuy Trieu Lagoon from 2013 to 2016 were downloaded from the United States Geological Survey (USGS) (http://earthexplorer.usgs.gov/).

Satellite images were processed by ENVI 5.1. software. Simultaneously, ArcGIS 10.2.2 was used to create maps and interpolate turbidity. SWAN modeling version 41.01 was also used to investigate potential areas appearing resuspension. Bathymetric data was obtained from Institute of Oceanography, Vietnam.

Meteorological data were downloaded from NCEP FNL, USA.

2.3 Methods

In order to convert digital number (DN) values of each pixel into turbidity, Landsat 8 OLI images were processed in two main steps (i) radiometric calibration, converting from DN value to radiance value and (ii) atmospheric correction to eliminate the influence of atmospheric absorption and scattering by using FLAASH integrated in ENVI software. Once the image is calibrated in remote sensing reflectance, Rrs, just about the water, it is possible to apply directly the relationship water quality parameters-Rrs computed with a training set of in situ point data to obtain a gridded image of turbidity (Ouillon et al., 2004).

Bottom shear stress was calculated by using SWAN model in other to determine potential resuspension areas, the major process affecting the spatiotemporal variation of turbidity in shallow waters.

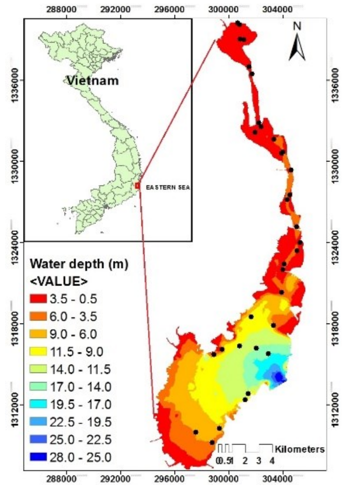

Figure 1. Sampling stations in 2015 and 2016 and location map of Thuy Trieu Lagoon and Cam Ranh Bay in Vietnam

R^2 coefficient was used to investigate the strength of the association between two variables. Root mean square error and scatter index were used to assess the accuracy of turbidity models.

2.4 Field observation

Field measurements were acquired in Cam Ranh Bay and Thuy Trieu Lagoon in two years 2015 (16 – 19 September) and 2016 (11–13 February) at random locations (Fig. 1) selected by visual analysis on the field. Field surveys were to measure water parameters including Total suspended solid (TSS), Chlorophyll-a, Organic suspended solid (OSS), Inorganic suspended solid (ISS), and sediment samples to measure grain size distribution. Simultaneously, TriOS RAMSES was used to measure radiance and irradiance so that calculating remote sensing reflectance, an important parameter used to assess water quality. AAQ sensor was used *in situ* on the second field observation for measuring turbidity, chlorophyll, temperature.

Water depths were measured by Hondex PS – 7 portable handheld depth sounder.

3. Results and Discussion

3.1. Turbidity model and verification

Linear regression with high R^2 was to develop a relation between *in situ* measurements and the space-based observations, remote sensing reflectance (**Rrs**) (Fig. 2).

Turbidity = 380.32*Rrs(B4) – 1.7826

R^2 = 0.836 and p < 0.001

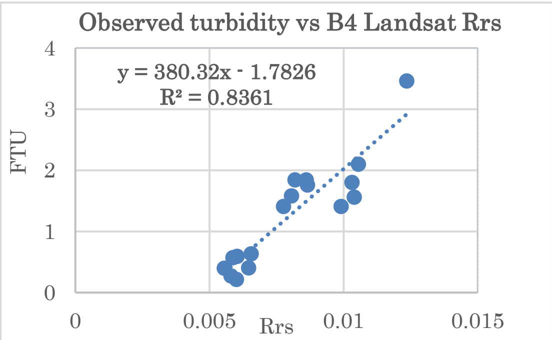

Figure 2: Correlation between remote sensing and *in situ* turbidity measurements (Feb. 11-13 2016)

3.2 Model verification

A comparison shown in Fig. 3 between Landsat 8 OLI estimates of turbidity and concurrent measurements at 17 stations indicated that the agreement between computed and observed turbidity was good. Scatter index (SI) and Root Mean Square Error (RMSE) were used to quantify the performance of the computed data.

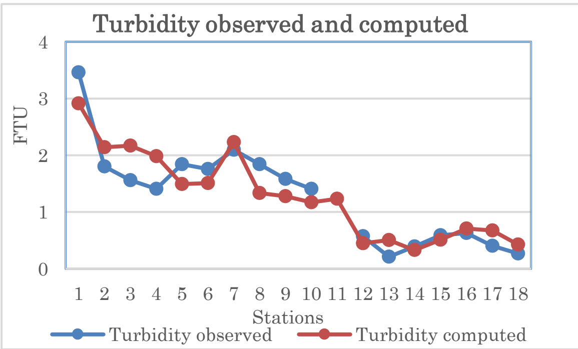

Figure 3: Comparison between observed (Feb. 14 2016) and computed turbidity

The results show that RMSE was 0.279 and SI was 0.217. These results indicated that the proposed model could be used with satisfactory performance to retrieve turbidity in Cam Ranh Bay and Thuy Trieu Lagoon.

3.3 Spatiotemporal variation of turbidity and its controlling factors, processes.

By using above algorithm, remote sensing reflectance of each pixel was converted into turbidity. The temporal variation of turbidity is presented in Fig. 4.

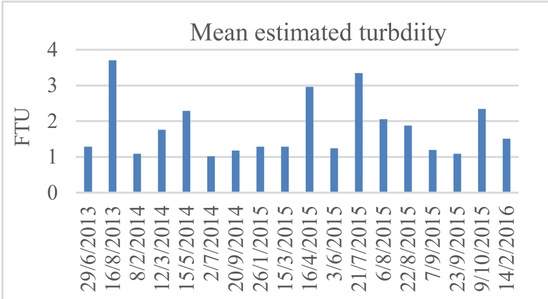

Figure 4: The variation of mean estimated turbidity of whole study area from 2013 to 2016

It reveals that the turbidity had significantly temporal variability from 2013 to 2016. The lowest mean turbidity appeared in dry season 1.018 FTU (July 2 2014) and the highest mean turbidity occurred shortly after raining 3.679 FTU (Aug. 16 2013).

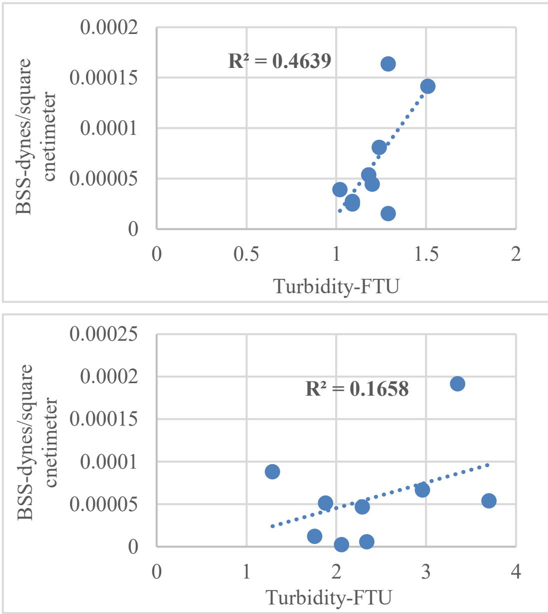

Figure 5: The correlation between mean estimated turbidity and bed shear stress (BSS) with small (top) and high rainfall conditions (below)

Figure 5 proved that the variation of turbidity concentration was mainly governed by resuspension bed sediment when there was no rain. However, when large amount of precipitation happened, resuspension became a minor factor affecting turbidity in Cam Ranh Bay and Thuy Trieu Lagoon.

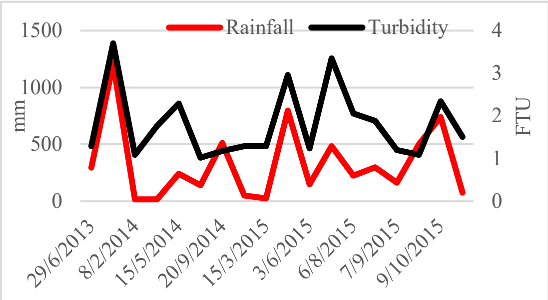

Figure 6: The correlation between rainfall and mean estimated turbidity

Among the variety of factors affecting the turbidity concentration (Fig. 6), $R^2 = 0.5397$ ($p < 0.05$, t-test) was considerably high correlation. The correlation between amount of precipitation of ten days and mean turbidity concentration was significant because p value was less than 0.05. Turbidity in the Bay contributed from the rivers was strongly influenced by amount precipitation.

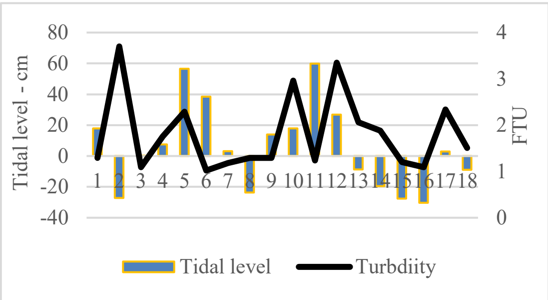

Figure 7: The correlation between mean estimated turbidity and tidal level at the bay mouth

During flood tide, a large amount of clear ocean water from the sea entered and diluted turbid waters of the bay (Fig. 7). As a result, turbidity concentration in Cam Ranh Bay and Thuy Trieu lagoon was decreased. Tide influences the water depth which might in turn affect the resuspension bed sediment in shallow waters through wave formation and intensity. As a result, turbidity was higher in shallow waters during ebb tide than the one in flood tide.

4. Conclusions

There is a high correlation between turbidity and Rrs of Landsat 8 OLI ($R^2 = 0.836$) after atmospheric correction.

A good agreement between observed and computed turbidity by using Landsat 8 OLI with low RMSE of 0.279 and SI of 0.217 after modeling verification.

Turbidity in Cam Ranh Bay and Thuy Trieu Lagoon was controlled by three main processes/ factors: (1) Resuspension bed sediment occurs in shallow waters, Thuy Trieu Lagoon and shorelines. During the dry season without raining, resuspension is the main process controlling turbidity. (2) The amount of precipitation regardless of the rainy or dry season is the main factor impacting the turbidity the study area. (3) Tidal regime is also a major factor affecting turbidity pattern in Cam Ranh Bay especially in rainy season or shortly after raining. The water becomes clearer and low turbidity during flood tide. In contrast, during ebb tide, total suspended matter is increased and results in high turbidity.

5. References

Allan, M. G., Hamilton, D. P., Hicks, B. J. and Brabyn, L., 2011. International Journal of Remote Sensing, vol. 32, No. 7, pp. 2037-2055, doi: 10.1080/01431161003645840.

Carson, A. B., Benjamin, M. J., Krista, K. B., Daniel, B. Y. and Christian, E. Z., 2015. Journal of Remote Sensing, vol. 7, pp. 13692-13710, doi:10.3390/rs71013692.

Dogliotti, A. I., Ruddick, K. G., Nechad, B., Doxaran, D. and Knaeps, E., 2015. Journal of Remote Sensing of Environment, vol. 156, pp. 157–168, doi.org/10.1016/j.rse.2014.09.020.

Güttler, F. N., Niculescu, S. and Gohin, F.., 2013. Journal of Remote Sensing of Environment, vol. 132, pp. 86–101, doi.org/10.1016/j.rse.2013.01.009.

Gernez, P., Barille L., Lerouxel A., Mazeran C., Lucas A. and Doxaran D., 2014. Journal of Geophys. Res. Oceans, vol. 119, pp. 7277–7294, doi:10.1002/2014JC010055.

Minnesota Pollution Control Agency, 2008. Turbidity: Description, Impact on Water Quality, Sources, Measures - A General Overview.

Ouillon, S., Douillet, P. and Andrefouet, S., 2004. Journal of Coral Reefs, vol. 23, pp. 109–122, doi 10.1007/s00338-003-0352-z.

Zheng, G. J., 2007. ISBN 978-0-470-13543-3.