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Satellite remote sensing for estimating water content and organic matter distributions in estuary sediments

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1. Introduction

Tidal flat, the submerged and exposed daily coastal wetland, is a deposition field of sedimentary materials by tides or rivers. It also has an important role for trapping and filtering sediments and suspended contaminants from discharged river water. Recently, several studies have addressed a significant relationship between the reflectance of electromagnetic waves and tidal flats' sediment properties such as sediment organic matter (Kaplan and Milliken, 2014) and water content (Lobell and Asner, 2002; Small et al., 2009; Ngoc et al., 2013). Additionally, the use of satellite imagery and different classification techniques have demonstrated effectively to map the distribution of water content of sediments (Rainey et al., 2000). Therefore, satellite remote sensing is a promising method for monitoring the changes of sediment properties and coastal geo-environments.

2. Materials and methods

The Van Uc estuary belonging to the Thai Binh river is situated in the northern part of the Red River Delta coastal zone in the north of Vietnam. As the discharged area of the Thai Binh river system, this area has complex environment components with mangrove and intertidal eco-systems (Fig. 1).

Total 20 sediment samples were taken from the tidal flat of Van Uc estuary on 17 December 2017 by spoon and preserved in plastic bags under cool condition after measuring their reflectance spectra by the field spectrometers RS^3. In a laboratory, all samples were measured continually for their reflectances under dry and wet conditions.

All samples were dried at 105^{o}C for 24h in an electric oven to detect the water content as follow:

$$w = \frac{m_1 - m_0}{m_0 - m_c} \times 100$$

where w is water content of sample (%), m_c is the weight of cup containing sample (g), m_1 is the weight of wet sediment with cup (g), and m_0 is the weight of dry sample with cup (g).

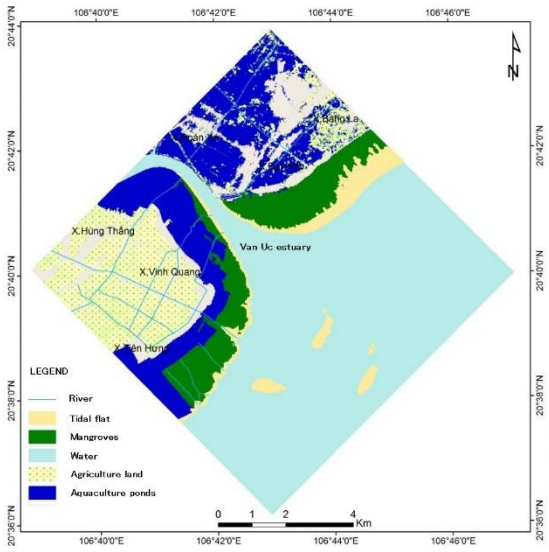

Figure 1. Land covers in the Van Uc estuary in which mudflat area is colored yellow.

Total samples were also divided into several parts for adding water to take more samples at different situations from dry to saturation. Then, they were dried at 550^{0}C for 5h in an electric oven to measure the organic matter from the next equation:

$$om = \frac{m_1 - m_2}{m_1 - m_c} \times 100$$

where om is organic matter of sample (%), m_c is the weight of cup containing sample (g), m_1 is the weight of dry sediment with cup before dry at 550^{0}C (g), and m_2 is the weight of dry sample with cup after dry at 550^{0}C (g).

Sentinel 2A (S2A), one of the Earth observation satellites has a multi-spectral imager including 13 spectral bands spanning from the visible blue to shortwave infrared (SWIR) region. The S2A image used in this study was acquired at 17:46 GMT on 25 September 2016 at the UTM zone 48N with 10, 20, and 60 m resolutions. The S2A Toolbox in the Sentinel Application Platform ver. 5.0 on Windows 10 was used to resample the image at the 10 m resolution. Then, a traditional empirical line method was applied as an atmospheric correction of the S2A scene. Finally, the

distribution map of sediment properties was generated by the density slicing tool of ENVI 5.3 and ArcGIS 10.5.

3. Results and discussion

The measured water contents of all samples were distributed widely from dry condition (0 %) to saturated condition (54.7 %). The organic matter contents were also ranged from 2.91 % to 7.67 %. The measured reflectance spectra of all the sediment samples at different water contents were in the range from visible to SWIR region. Obviously, the reflectance spectra of dry samples are higher than the wet samples, and the reflectance spectra of samples at dry condition have the same trend in that they increase with the wavelength.

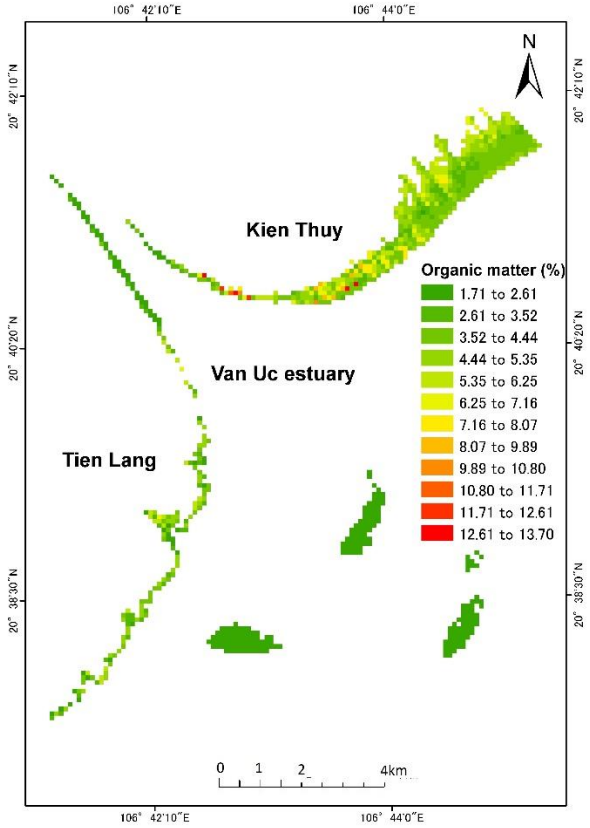

Figure 2. Distribution map of organic matter estimated from Sentinel 2A acquired on 25th September 2016.

There was a small correlation between the water content and the simulated S2A single band reflectance in the total wavelength range with R (correlation coefficient) smaller than 0.5. On the other hand, most band ratios of the simulated S2A had strong correlation with the water content. The highest R was for the relationship of water content with the band ratio of NIR (band 8a, B8a) and SWI (band 11, B11) with R = 0.84. Therefore, it can be estimated water content from the ratio of S2A band 8a versus band 11 by the next equation:

$$WC\,(\%) = [\ln (B8a/B11) - \ln 0.9135)]/0.0143 \quad (1)$$

where WC is the water content of the surface sediment of tidal flats (%).

The organic matter had weak correlated with the simulated S2A single band reflectance, because their Rs were from 0.1 to 0.4. On the contrary, the organic matters were well correlated with the *in-situ* S2A band ratios with higher R. The maximum R was specified for the relationship between the organic matter and the ratio of the band in NIR (B7) versus the band in visible deep blue (B1) with R = 0.9. Accordingly, the most suitable equation to estimate the organic matter from the ratio of S2A band 7 versus band 1 is expressed as:

$$OM\,(\%) = 0.0134\ e^{\,1.0045(B7/B1)} \quad (2)$$

where OM is the organic matter in the tidal flat sediment (%).

Applying Equations (1) and (2) to the S2A image scene acquired on 25th June 2018, distributions of water content and organic matter in the surface sediments in the study area were mapped (Fig. 2). The water contents are distributed from 0 to 50.1 % and have the trend with the highest value near the shoreline Tien Lang, while the lowest value was located in the north tidal flat and some small areas in the middle estuary. The organic matters are ranged from 2% to 8.2% with the highest along the inland and decreasing toward the off-shore.

4. Conclusion

A strong correlation was clarified between the *in-situ* reflectance spectra data and the sediment features of the surface sediment samples in the Van Uc estuary. The result confirmed the strong effect of the water content and organic matter on the reflectance spectra and the potential of Sentinel 2A band ratio to estimate the distribution of them in the surface sediments in tidal flat of the estuary.

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