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ESTIMATION OF SUSPENDED SEDIMENT CONCENTRATION USING VNREDSAT – 1A MULTISPECTRAL DATA, A CASE STUDY IN RED RIVER, HANOI, VIETNAM

ABSTRACT. The traditional methods for measuring water quality variables are time-consuming and do not give a synoptic view of a water body or, more significantly, a synoptic view of different water bodies across the landscape. However, remote sensing technology with advantages such as wide area coverage and short revisit interval have been effectively used for environmental pollution applications, such as for monitoring water quality parameters. Many studies around the world show that optical satellite imagery can be used effectively in evaluating suspended sediment concentration. This article presents results of monitoring suspended sediment concentration in Red River, Hanoi, Vietnam through ground truth measurements and VNREDSat-1A multispectral data. The results obtained in the study can be used to serve the management, monitoring and evaluation of surface water quality.

KEY WORDS: remote sensing, multispectral image, suspended sediment, surface water quality, VNREDSat-1A

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INTRODUCTION

The quality of surface water is a major concern around the world. The major factors affecting surface water quality are suspended sediments (Chalov et al. 2017), chlorophyll, nutrients and pesticides (Ritchie et al. 1990). Remote sensing technique can be an efficient tool for mapping terrigeneous substances in surface water, and hence provide information to help managers in monitoring and controlling water quality. Although the digital numbers and radiance of satellite imagery (Ritchie et al. 1987) have been used to indicate surface water quality parameters, reflectance is more widely used, because the model based on the reflectance value can be applied to other satellite images. Most algorithms used for calculating water quality parameters were based on the reflectance model, which is a function of the inherent optical properties of water, and these in turn can be related to the concentration of the water quality parameters (Lim et al. 2009; Wang and Tian 2013). Many domestic and foreign studies show that the reflectance of surface water, which determined from optical remote sensed data is strongly correlated with the concentration of water quality parameters (Frohn and Autrey 2007; Gilerson et al. 2010; Ritche et al. 1974), icluding suspended sediment (Mobley 1994; Ritchie and Cooper 1988; He et al. 2008; Nguyen et al. 2016; Markert et al. 2018). Therefore, optical satellite imagery has been used effectively for the assessment and monitoring of suspended sediment concentration.

The relationship between Landsat data and suspended sediment concentration has been proven by many researchers (Chalov et al. 2017; Olet 2010; Ritchie et al. 1990; Wang et al. 2009; Zhou et al. 2006; Trinh and Tarasov 2016; Wakerman et al. 2017; Yepez et al. 2018). In the study (Doxaran et al. 2006), the authors used the ratio of the near-infrared and green bands of Landsat ETM+ multispectral images to determine concentration of suspended sediment and turbidity in the Gironde estuary (southest France). In the study (Trinh and Tarasov 2016), the authors used Landsat 7 ETM+ data and 10 ground truth sampling stations for calculating suspended sediment concentration in Tri An reservoir, Vietnam. Li et al. describe an empirical algorithm using MODIS data to identify areas with suspended sediments in turbid waters and shallow waters with bottom reflections (Li et al. 2003). MODIS data also used in study (Guzman and Santaella 2009) to calculate concentration of suspended sediment in Mayaguez Bay (Puerto Rico). Chen et al. have used EO-ALI satellite imagery and found negative regression model between water turbidity in the Pearl River Estuary and reflectance at 570 nm (Chen et al. 2009).

Today, many satellites with high enought spatial resolution have been used in water quality monitoring studies. For instance, Nguyen et al. found that the ratio of band 5 and band 4 using Sentinel-2A multispectral image yielded a good estimation of chlorophyll-a and suspended sediment in West Lake, Hanoi, Vietnam (Nguyen et al. 2016). Doxaran et al. (2002), Gernez et al. (2015) investigated the relationship between suspended sediment concentration and spectral paramerters of SPOT 4 and SPOT 5 sensors data. Sentinel 2 MSI data was used in study (Liu et al. 2017) to retrieve suspended particulate matter concentrations in Poyang lake (China).

Because each river has a unique spectral characteristics, models for calculating suspended sediment concentration must be created for each of them. This study focused on established and analyzed the VNREDSat-1A multispectral imagery to retrieve suspended sediment concentration on the Red river in Hanoi city, Vietnam.

THE STUDY AREA

The selected study area is the Red river in Hanoi city, Vietnam (Fig. 1). Hanoi is the capital of Vietnam and the country's second biggest city. Its population in the year 2017 was estimated at 7.68 million people. With the rapid growth of industrialization in urban area, the surface water in Hanoi is getting more polluted. The weakness in industrial wastewater management is the main cause of water pollution. Industrial wastewater is directly discharged into lakes and rivers, causing serious pollution of surface water in Hanoi (Ministry of Natural Resources and Environment of Vietnam 2012). The observation data show that, suspended sediment concentration in surface water of Red river is high, with mean values greater than 90 mg/l in dry season.

MATERIALS AND METHODS

Remote sensing data

In this study, VNREDSat-1A multispectral image acquired in December 21, 2017 was collected (Fig. 2). VNREDSat-1A (Vietnam Natural Resources, Environment and

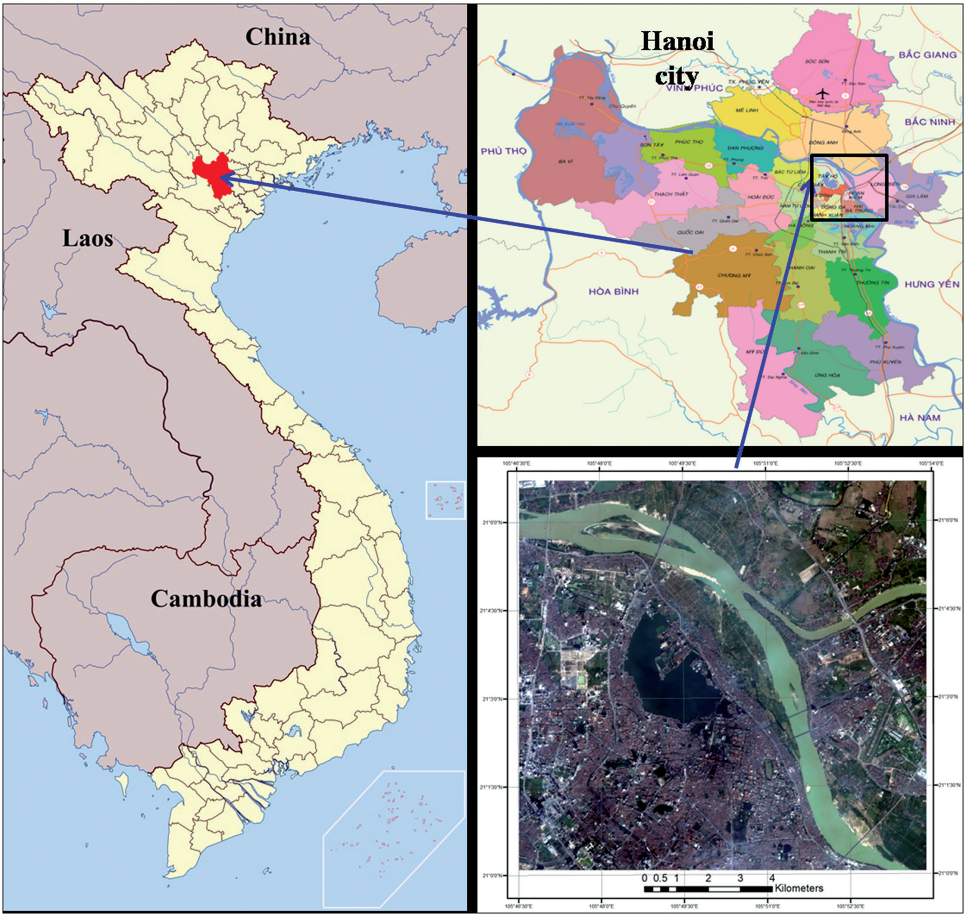

Fig. 1. The study area in Red river, Hanoi, Vietnam

Disaster Monitoring Satellite) is the first optical Earth observing satellite of Vietnam was successfully launched on May 5, 2013 at Guiana space centre by a Vega rocket. Its primary mission is to monitor and study the effects of climate change, predic and take measures to prevent natural disasters and optimise the management of Vietnam's natural resources. VNREDSat-1A has collected images using five spectral bands in different wavelengths of visible and near-infrared to observe a 17.5 kilometer wides swath of the Earth in 2.5 (panchromatic band) and 10 (multispectral bands) meter spatial resolution (Table 1). While the design life of VNREDSat-1A was only 5 years, this satellite is likely to produce imagery for a few more years (Vietnam Academy of Science and Technology 2018).

The necessary image pro-processing included radiometric correction, atmospheric correction, and geometric correction. The reflectance values were obtained from VNREDSat-1A image for all 15 water samples based on the GPS locations.

Ground truth data

The 15 representative water samples were collected during research cruises in the dry season in December 21, 2017 (Fig. 3), roughly coinciding with the time of VNREDSat-1A image acquisition. In the dry season, concentration of suspended sediment in surface water of Red river is often much lower than in the rainy season (Ministry of Natural Resources and Environment of Vietnam, 2012). These samples evenly distributed in the study

Table 1. Characteristic of VNREDSat-1A multispectral image

STT	Band name	Bandwidth (μm)	Resolution (m)
1	Band 1 (blue)	0.45 – 0.52	10
2	Band 2 (green)	0.53 – 0.60	10
3	Band 3 (red)	0.62 – 0.69	10
4	Band 4 (near infrared)	0.76 – 0.89	10
5	Band 5 (panchromatic)	0.45 – 0.75	2.5 (at nadir)

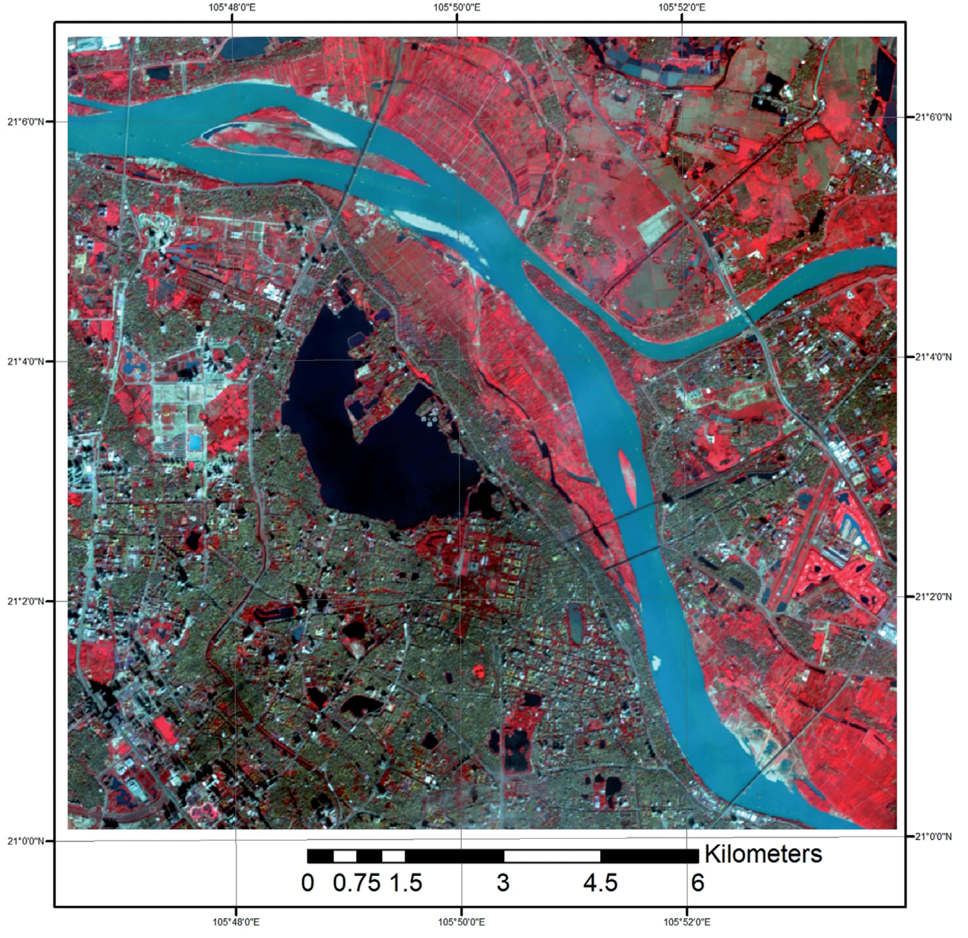

Fig. 2. VNREDSat-1A multispectral image in Hanoi city, December 21, 2017, RGB:432

area (Fig. 2). In order to ensure accuracy, the sampling position should be as close as possible to the part which satellite observes directly (Wang and Ma 2001; Nguyen et al. 2016). Thus, these 15 surface water samples were collected for each site just beneath the surface.

The water samples are stored in dark plastic bottles and analyzed in the lab. The sampling and chemical analyses were on the standard methodology. The concentration of suspended sediment was determined using water filtration method (Ministry of Natural Resources and Environment of Vietnam 2015). The 11 water samples were randomly selected from 15 total samples for modeling and the remaining 4 samples for verification. In addition, in this study we also used 2 water samples which collected by the end of December, 2017 to evaluate accuracy of regression model. The authors also collected 27 other water samples in dry season (April 28, 2018) to evaluate the spatial distribution of suspended sediment concentrations in Red river. These water samples are not used for regression due to not collected in time of satellite image acquisition. Table 2 shows the coordinates of all water sampling points and concentration of suspended sediment (mg/l).

METHODOLOGY

In the first step, the digital number of VNREDSat-1A multispectal bands is converted to spectral radiance using the sensor calibration parameters by the following equation:

$$L_\lambda = Gain \cdot DN + Bias \quad (1)$$

Where:

L_λ – spectral radiance at the sensor's aperture in watts/m^2.ster.μm;

Gain – rescaling gain factor for each band;

Bias – rescaling bias factor for each band;

DN – the quantized calibrated pixel value in digital number.

Gain and Bias factors are found for each band from metadata file of the VNREDSat-1A data (Table 3).

In the second step, the theoretical radiance of a "dark object" is computed with the theoretical reflectance of 1% as proposed

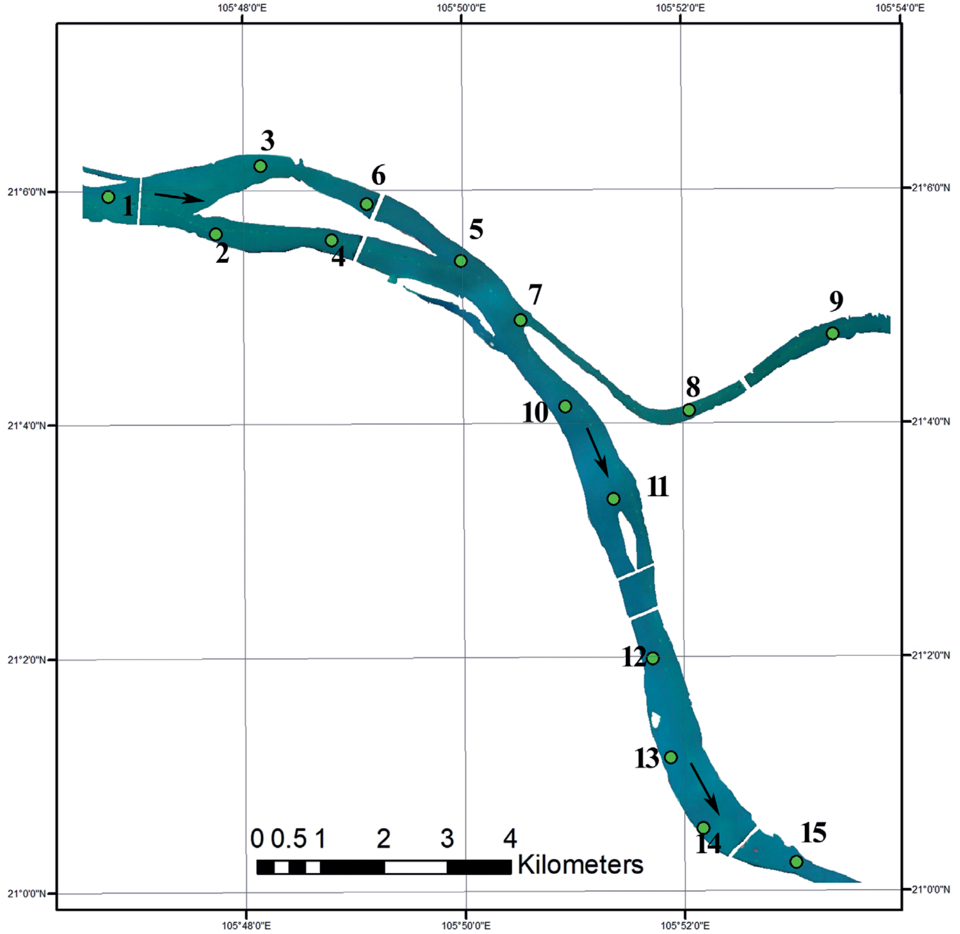

Fig. 3. Location of the water quality monitoring points

Table 2. Ground truth data of suspended sediment concentration

Sampling locations	Coordinates (m)		Concentration of suspended sediment (mg/l)
	X	Y	
1	580960	2333334	70
2	582656	2332738	88
3	583366	2333815	91
4	584488	2332646	97
5	586527	2332326	95
6	585038	2333219	98
7	587466	2331386	102
8	590124	2329966	100
9	588175	2329859	97
10	592392	2331180	99
11	588932	2328569	98
12	589560	2326058	112
13	589842	2324488	115
14	590354	2323379	99
15	591819	2322842	108
P1	590466	2323234	75
P2	590629	2323012	91

Table 3. VNREDsat-1A spectral radiance range

No.	Band name	Gain (watts/(m2.ster.µm/DN)	Bias (watts/(m2.ster.µm)
1	Band 1 (blue)	1.6382548072236700	0.0000
2	Band 2 (green)	1.6213056650501201	0.0000
3	Band 3 (red)	1.8478962570830899	0.0000
4	Band 4 (near infrared)	2.5112173640667201	0.0000

by Chavez (1988, 1996) and Moran et al. (1992):

$$L_{\lambda 1\%} = \frac{0.01 \cdot \cos(\theta_s) \cdot d^2}{\pi \cdot ESUN_\lambda} \quad (2)$$

Where:
$ESUN_\lambda$ – the mean exoatmospheric solar spectral irradiance (watt/m2.ster.µm);
θ_s – the solar zenith angle in degrees;
d – Earth - Sun distance in astronomical units.

Step 3 computes a value for the haze that may be present in the image:

$$L_{\lambda haze} = L_\lambda - L_{\lambda 1\%} \quad (3)$$

The last step converts spectral radiance to surface reflectance values. Surface reflectance can be calculated using following equation:

$$\rho = \frac{\pi \cdot d^2 \cdot (L_\lambda - L_{\lambda 1\%})}{ESUN_\lambda \cdot \cos(\theta_s)} \quad (4)$$

After atmospheric correction, geometric correction was applied to the VNREDSat-1A image by using ground control points collected in fieldwork. Image processing was done at the Department of National Remote Sensing (Vietnam). In turbid sediment-dominated water, the reflectance of visible and near infrared bands are highly correlated to ground truth measurements data (Doxaran et al. 2007; Trinh 2016). In this study, we used the reflectance values of VNREDSat-1A visible and near infrared bands, and ground truth data to build the regression model for calculating concentration of suspended sediment. The topographic map of Hanoi (scale of 1:25 000) was used to extract boundary of Red river, and then created the water mask using ERDAS Imagine 2014 program.

RESULTS AND DISSCUSSION

Based on the multispectral band of VNREDSat-1A image on December 21, 2017, the retrieval models were applied to predict the spatial distributions of suspended sediment over the Red river in Hanoi, Vietnam. Good relationships for suspended sediment and reflectance values were found in multiple linear regressions using all four multispectral bands. Regression analysis is performed using Data Analysis tool in Microsoft Excel 2013.

In order to find the best model, model for estimating suspended sediment concentration have been selected following equation:

$$TSS\left(\frac{mg}{l}\right) = 1953.588\lambda_1 + 1311.897\lambda_2 \ldots$$
$$-1150.910\lambda_3 + 585.871\lambda_4 - 251.769 \quad (5)$$

Where: λ_1, λ_2, λ_3, λ_4 are surface reflectance values of blue, green, red and near-infrared bands of VNREDSat-1A multispectral image. In this model, multiple R is 0.905, R-square is 0.909 and RMSE (Root Mean Square Error) is 3.664 (mg/l).

To convert the digital numbers of VNREDSat-1A image into suspended sediment concentration we use the calculating module of ERDAS Imagine 2014. To show how the empirical relation (equation 5) behaves when applied to the surface water, we extract the suspended sediment concentration distribution map (Fig. 4) for regions in Red river of Hanoi city, Vietnam. The modeling results for suspended sediment concentration are shown in Fig. 4.

In this study, 4 water samples (sampling locations No. 2, 6, 9 and 15) and two other water samples (P1 and P2) was used to evaluate the accuracy of the regression model. Comparison between concentration of suspended sediment at the measurement points and the results calculated from the VNREDSat-1A satellite image is presented in Table 4. It can be seen, the difference between concentration of suspended sediment calculated from remote sensing imagery and ground truth data range from 1.12 – 8.40%.

Table 4. Comparison of suspended sediment concentration estimated using VNREDsat-1A image and ground truth data

No. sampling locations	Suspended sediment concentration (mg/l)		Difference (mg/l)
	Ground truth data	From remote sensing imagery	
2	88	89.0	1.0
6	98	94.1	-3.9
9	97	102.7	5.7
15	108	105.3	-2.7
P1	75	81.3	6.3
P2	91	88.2	-2.8

The distribution map of suspended sediment concentration in Red river (Hanoi city, Vietnam) is shown in Figure 4. In this example, the estimation of suspended sediment concentration ranges from 67.9 to 142.6 (mg/l). In Fig. 4, ten zones of suspended sediment concentration are identified using the "natural breaks" classification method in ArcGIS 10 program with the following values: 68 – 85, 85 – 93, 93 – 96, 96 – 99, 99 – 102, 102 – 104, 104 – 108, 108 – 112, 112 – 120 and 120 – 143 (mg/l). The brown pixels represent areas with high concentration of suspended sediment. Meanwhile, areas with low concentrations of suspended sediment are represented by blue colored pixels.

The results show that, the surface water in Red river (Hanoi, Vietnam) has high concentration of suspended sediment, especially in the south of the study area. This can be explained by the effects of agricultural production (the central part of the study area and the east coast of the south part of the study area). Besides, surface water quality in the southern part of study area is also highly affected by domestic and industrial waste water from the inner of Hanoi city. Meanwhile, the suspended sediment concentration in the north part of the study area (suburban area) is low due to less influence of domestic and industrial waste water.

In this case, all surface water of Red river has concentration of suspended sediment greater than 50 (mg/l), so is higher than permitted standards when compared with Vietnam National technical regulations on surface water quality. The obtained results in this study indicate that the surface water of Red river is only suitable for irrigation purposes or similar water quality purposes with low quality water requirements. The

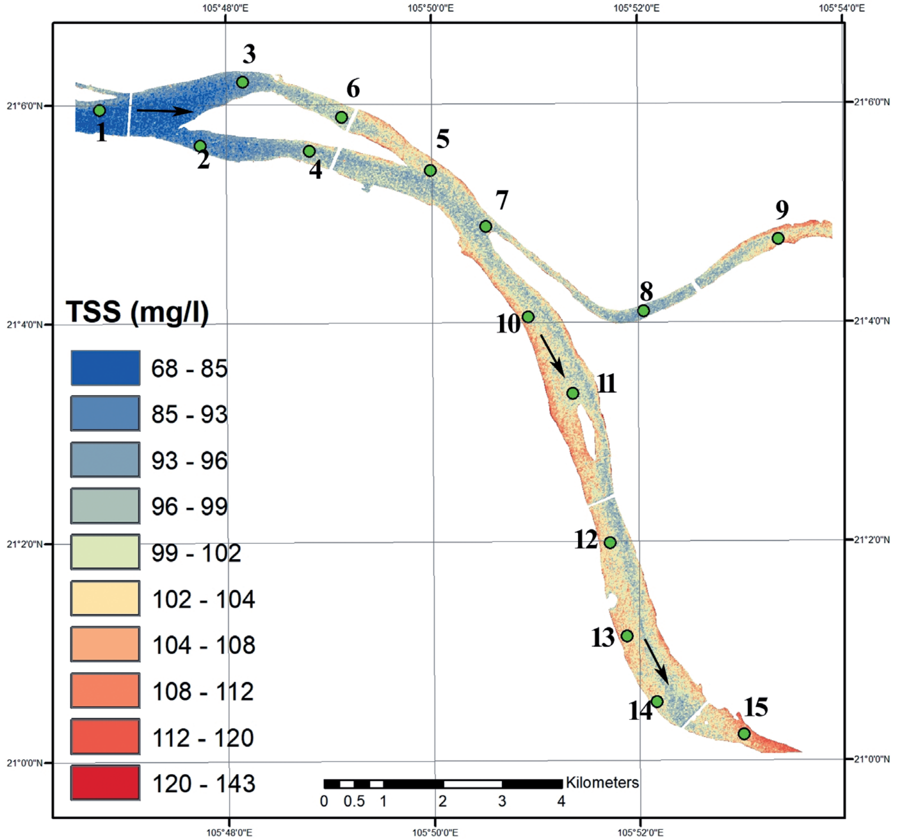

Fig. 4. Spatial distribution of model retrieval result with VNREDSat-1A image of December 21, 2017 for suspended sediment

results obtained in this study were also consistent with the suspended sediment concentrations distribution in 27 water samples of Red River, which collected in dry season (April 28, 2018). In these water samples, the minimum and maximum suspended sediment concentration was 65 mg/l and 170 mg/l, respectively.

CONCLUSION

Nowadays, water pollution has become a global issue, directly caused by human populations grow, industrial and agricultural activities. This study showed that there existed a statistical significant correlation between reflectance values of VNREDSat-1A data and concentration of suspended sediment in surface water of Red river, Hanoi (Vietnam). The square of the correlation coefficient (R2) in this example was 0.909. In this study, we used 4 water samples to verify regression model. Overall, there is a very good correlation between the concentration of suspended sediment calculated from remote sensing imagery and ground truth data.

The obtained model for calculating suspended sediment concentration in this study (equation 5) can be used for surface water monitoring in the future not only for the Red river, but also for other similar rivers. In the case of multi-temporal datasets, the necessary radiometric normalization is applied to empirically reducing the differences between images in time series or mosaics related to differences in the image acquisition time or date. This result can also be applied to the same remote sensing data, such as SPOT 5 image.

Remote sensing was further confirmed to be very useful on establishing a time-cost effective method for the routine monitoring of surface water body. The obtained results in this study are an important source of information for managers in the assessment, monitoring and sustainable use of surface water resources.

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