ISSN 0001-4338, Izvestiya, Atmospheric and Oceanic Physics, 2020, Vol. 56, No. 12, pp. 1645–1651. © Pleiades Publishing, Ltd., 2020.
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# Determining the Concentration of Suspended Sediment in the Lower Đáy River (Northern Vietnam) Using MSI Sentinel 2 High Spatial Resolution Data

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Received November 15, 2019; revised December 15, 2019; accepted February 7, 2020

**Abstract**—The concentration of suspended sediment is an important parameter in assessing the quality of surface waters. Many studies have shown that reflectance from remote sensing data is strongly related to the concentration of suspended sediment. Results are presented from determining the concentration of suspended sediment in the surface water of Đáy River in northern Vietnam using Sentinel 2 multispectral images with a spatial resolution of 10 meters. The reflectance of the water's surface, calculated on the basis of the visible and near-infrared channels of the Sentinel 2 image, are compared to in situ data. Regression models are developed on the basis of relationship between the reflectance and the concentration of suspended sediment. The best linear equation among the models is chosen to quantitatively assess the pollution of surface water in this river basin. The results can be used to monitor, evaluate, and manage the quality of surface water.

*Keywords:* remote sensing, Sentinel 2, water pollution, suspended sediment, Đáy River

**DOI:** 10.1134/S0001433820120397

## INTRODUCTION

Remote sensing technologies are widely used around the world to monitor and assess surface water quality with high accuracy, saving time and money (Gholizadeh et al., 2016). In Russia, the first works on the possibility of studying the propagation of suspended matter based on remote sensing data appeared in the mid-1970s and early 1980s. (Labutina et al., 1976; Labutina and Safyanov, 1980). Initial studies were aimed mainly at studying the relationship between coefficients of brightness obtained by analyzing satellite images on the one hand and the concentration of suspended matter on the other, along with other parameters for assessing water quality (Ritchie et al., 1976; Chen et al., 1992; Dekker et al., 1996).

Many researchers have found a linear relationship between spectral reflectivity and such surface water quality parameters as particulate matter (TSS), chlorophyll-a (Ritchie et al., 1987; Ritchie et al., 1990; Chen et al., 1991; Moran et al., 1992). In other studies (He, 2008; Doxaran, 2007; Guzman et al., 2009), the authors used multispectral satellite images with different spatial resolutions (Landsat, Spot, MODIS) to determine the concentration of suspended solids in surface waters. Studies using multispectral imagery data to assess water quality were performed in the Quang Ninh–Hai Phong coastal region of Vietnam (Luong, 2014). The surface waters of Lake Chian, southern Vietnam (Chin and Tarasov, 2016), Lake West, Hanoi (Nguyen et al., 2016), and the water of the Red River (Trinh et al., 2018; Pham et al., 2018) were also studied. The possibility of building maps of the distribution of suspended matter in the southern part of Lake Baikal was also demonstrated (Labutina and Tarasov, 2018), allowing us to estimate the distribution of solid runoff along the channels of the Selenga delta, depending on the time and phase of the water regime.

The European Space Agency's Copernicus program includes two Earth observing satellites (Sentinel 2A and Sentinel 2B) that provide images in 13 spectral channels in the range of 0.443–2190 μm (Pahlevan et al., 2017). Table 1 shows the spectral and spatial characteristics of a multispectral image obtained by the Multi-Spectral Instrument (MSI) equipment installed on the Sentinel 2 satellite. The Sentinel 2 system has a 5-day update period for information that is provided free of charge to interested users.

Space sensors of the Sentinel 2 system were used in studies by Liu et al. (2017), Caballero et al. (2018) Elhag et al. (2019), and Ghirardi et al. (2019) to determine the concentration of suspended solids in surface waters. The above works showed that MSI Sentinel 2 imaging is a very valuable resource for environmental research and monitoring, including surface water quality assessment.


**Fig. 1.** Location of the studied area and water sampling points.

## INITIAL DATA AND PROCEDURES

### *Initial Data*

The Đáy River is located in the southwestern part of the Red River Delta. It is one of the largest rivers in northern Vietnam. Its length is about 240 km, and it flows through 5 provinces with the administrative centers of Hanoi, Hoa Binh, Ha Nam, Ninh Binh, and Nam Dinh. The area of the river basin is 5800 km$^2$. The width of the river varies from 40 m in its narrowest part (in the area of Hanoi) to 875 m in the widest part (near its mouth). The average depth of the river is 7 m. Increasing pollution of the surface waters of the river has been observed constantly since 2000, due to the construction of industrial enterprises and the growing extraction of natural resources in the surrounding area. Studying and applying modern monitoring technologies to assessing the quality of surface water in a given territory is an important practical issue, the resolving of which will provide timely information to local authorities and allow the sustainable use of surface water resources to be implemented.

The MSI Sentinel 2A multispectral image (code S2A_MSIL1C_20180409T032541_N0206_R018_T48QXH 20180409T070457) obtained on April 9, 2018, (Fig. 1) was selected as the initial data. This image was processed for purposes of geometric and

**Table 1.** MSI multi-area imaging features

| Channel | Spectral range, μm | Spatial resolution, m |
|---|---|---|
| 1 | 0.421–0.457 | 60 |
| 2 | 0.439–0.535 | 10 |
| 3 | 0.537–0.582 | 10 |
| 4 | 0.646–0.685 | 10 |
| 5 | 0.694–0.714 | 20 |
| 6 | 0.731–0.749 | 20 |
| 7 | 0.768–0.796 | 20 |
| 8 | 0.767–0.908 | 10 |
| 8a | 0.848–0.881 | 20 |
| 9 | 0.931–0.958 | 60 |
| 10 | 1.338–1.414 | 60 |
| 11 | 1.539–1.681 | 20 |
| 12 | 2.072–2.312 | 20 |

radiation correction. We used images in the visible and near infrared spectral ranges (0.439–0.535; 0.537–0.582; 0.646–0.685; 0.767–0.908 μm).

Ground data were obtained during the field work of a research expedition on April 9, 2018, in several areas along the river bed. Water samples were taken in the middle part of the river at depths of 0–25 cm using a horizontal Van Dorn Sampler with a volume of 4 L. The coordinates of the sampling points were determined using a GPS navigator device. Water samples were placed in a container with a temperature of 4°C and were immediately transferred to our laboratory for analysis. Sampling was done at 35 points (Fig. 1). The concentration of suspended matter in the water was determined via water filtration (Table 2) and examining the dry residue.

*Procedures*

The image from MSI Sentinel 2 (https://earthexplorer.usgs.gov/) was preliminarily processed to eliminate radiometric and geometric errors. The original pixel values of the image were converted to luma values using the SNAP Desktop software. Atmospheric correction was done with the Sen2Cor module via classical DOS (Dark Object Subtraction) (Chavez, 1988; Chavez, 1996) based on subtracting the pixel brightness of the darkest object in the image from the brightness of the image pixels.

Linear regression (Ritchie et al., 1987; Ritchie et al., 1990) was used to determine the relationship between the number of suspended particles obtained in field observations and the coefficients of luminance calculated from the Sentinel 2 multispectral imagery. Linear regression coefficients were calculated from spectral reflectance in the blue (*2*), green (*3*), red (*4*), and near infrared (*8*) channels of the MSI Sentinel 2 image and TSS (Total Suspended Solids) values in water samples. In this work, regression equations were based on one, two, three, and all four channels (*2*, *3*, *4*, *8*) of the MSI Sentinel 2 image. Using the equations obtained via $R^2$, the optimum regression function was selected to determine the concentration of suspended matter. A block diagram of the methodology for determining the concentration of suspended solids in surface waters using the Sentinel 2 satellite image is shown in Fig. 2.

## RESULTS AND DISCUSSION

Let us consider the regression equations obtained from the Sentinel 2 data for our object of study, the surface waters of the Đáy River. Data on the concentration of suspended matter in samples from 28 sections of the river were used to construct the regression equations. The remaining seven sections were used to assess the accuracy of the resulting regression model. Linear regression equations calculated for a different set of channels are presented in Table 3.

**Table 2.** Locations of water sampling sites and concentration of suspended particles (mg/L)

| Points | Coordinates | | TSS concentration (mg/L) |
|---|---|---|---|
| | latitude | longitude | |
| 1 | 20°34′26.0″ N | 105°52′11.0″ E | 24 |
| 2 | 20°34′19.0″ N | 105°53′23.0″ E | 26 |
| 3 | 20°33′14.0″ N | 105°53′41.0″ E | 22 |
| 4 | 20°32′36.6″ N | 105°54′29.1″ E | 27 |
| 5 | 20°32′33.9″ N | 105°54′31.8″ E | 28 |
| 6 | 20°32′34.3″ N | 105°54′35.9″ E | 28 |
| 7 | 20°32′36.8″ N | 105°54′37.5″ E | 28 |
| 8 | 20°31′46.3″ N | 105°54′44.9″ E | 26 |
| 9 | 20°30′44.0″ N | 105°54′24.0″ E | 25 |
| 10 | 20°29′41.3″ N | 105°53′37.1″ E | 25 |
| 11 | 20°28′37.5″ N | 105°53′23.2″ E | 28 |
| 12 | 20°24′27.0″ N | 105°54′26.0″ E | 28 |
| 13 | 20°22′27.5″ N | 105°54′57.3″ E | 26 |
| 14 | 20°21′17.4″ N | 105°57′10.9″ E | 24 |
| 15 | 20°19′41.7″ N | 105°56′08.4″ E | 24 |
| 16 | 20°19′37.7″ N | 105°56′10.0″ E | 29 |
| 17 | 20°18′38.2″ N | 105°58′05.7″ E | 30 |
| 18 | 20°15′47.0″ N | 105°58′52.0″ E | 31 |
| 19 | 20°15′43.8″ N | 105°58′59.0″ E | 29 |
| 20 | 20°15′06.4″ N | 106°01′59.1″ E | 30 |
| 21 | 20°15′07.2″ N | 106°02′48.6″ E | 30 |
| 22 | 20°13′27.4″ N | 106°02′12.0″ E | 33 |
| 23 | 20°15′18.0″ N | 106°05′27.0″ E | 35 |
| 24 | 20°15′02.0″ N | 106°05′55.0″ E | 36 |
| 25 | 20°15′02.6″ N | 106°05′51.4″ E | 36 |
| 26 | 20°12′60.0″ N | 106°06′31.0″ E | 33 |
| 27 | 20°12′08.7″ N | 106°09′34.8″ E | 32 |
| 28 | 20°07′23.0″ N | 106°09′44.0″ E | 33 |
| 29 | 20°07′21.0″ N | 106°09′38.0″ E | 35 |
| 30 | 20°05′45.0″ N | 106°08′43.0″ E | 35 |
| 31 | 20°03′22.0″ N | 106°07′53.0″ E | 40 |
| 32 | 20°02′59.5″ N | 106°07′00.5″ E | 36 |
| 33 | 20°03′01.3″ N | 106°06′58.7″ E | 36 |
| 34 | 20°00′21.1″ N | 106°06′27.4″ E | 37 |
| 35 | 19°58′56.8″ N | 106°05′54.4″ E | 36 |

Our results showed that the coefficient of determination ($R^2$) reached its highest value ($R^2 = 0.82$) as a linear regression function using all 4 channels (*2*, *3*, *4*, *8*) of the Sentinel 2 image. The best equation for calculating the concentration of suspended solids in the river's surface waters was thus

$$TSS\,(\text{mg/L}) = 741.5B_2 - 180.3B_3 + 96.2B_4 - 384.3B_8 - 21.1, \quad (1)$$

where $B_2$, $B_3$, $B_4$, and $B_8$ are the values of spectral brightness in channels *2*, *3*, *4*, and *8* of the Sentinel 2 images.

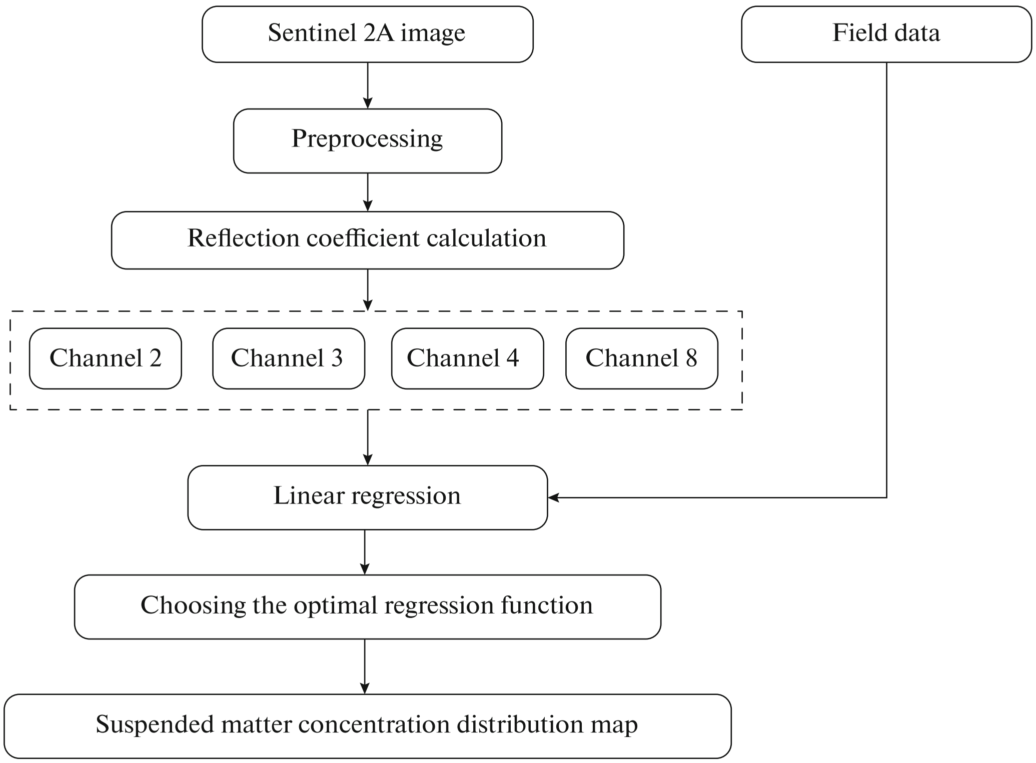


**Fig. 2.** Flowchart of the methodology for determining the concentration of suspended solids in surface waters, based on Sentinel 2 multi-zone survey data.

A comparison of the calculated (according to formula (1)) concentrations of suspended matter and those determined from the data of seven ground control sites are presented in Table 4. We can see that for all control sites, the error in determining the SPM concentration from the Sentinel 2 satellite image and the results from ground-based observations not very great. This error varies from 3.7 to 8.5%. These results testify to the possibility of determining suspended matter in river water with fairly high accuracy on the basis of the MSI Sentinel 2 multispectral image.

**Table 3.** Equations of the linear relationship between the concentration of suspended matter and the spectral brightness of the water surface

| No. | Spectral channels | Regression equations | $R^2$ |
|---|---|---|---|
| 1 | $B_2$ | $351.4B_2 - 14.0$ | 0.31 |
| 2 | $B_3$ | $254.4B_3 + 0.1$ | 0.42 |
| 3 | $B_4$ | $149.4B_4 + 14.3$ | 0.39 |
| 4 | $B_8$ | $-59.3B_8 + 34.2$ | 0.02 |
| 5 | $B_2$, $B_3$ | $-714.0B_2 + 685.7B_3 + 39.0$ | 0.50 |
| 6 | $B_2$, $B_4$ | $-57.2B_2 + 171.4B_4 + 19.2$ | 0.35 |
| 7 | $B_2$, $B_8$ | $665.6B_2 - 355.6B_8 - 31.3$ | 0.69 |
| 8 | $B_3$, $B_4$ | $468.8B_3 - 142.6B_4 - 10.0$ | 0.44 |
| 9 | $B_3$, $B_8$ | $-250.1B_3 + 357.5B_8 + 3.6$ | 0.66 |
| 10 | $B_4$, $B_8$ | $240.6B_4 - 293.2B_8 + 22.9$ | 0.65 |
| 11 | $B_2$, $B_3$, $B_4$ | $-666.2B_2 + 747.3B_3 + 60.2B_4 + 32.1$ | 0.50 |
| 12 | $B_2$, $B_3$, $B_8$ | $730.6B_2 - 36.4B_3 - 365.0B_8 - 34.4$ | 0.69 |
| 13 | $B_2$, $B_4$, $B_8$ | $530.6B_2 + 53.7B_4 - 347.7B_8 - 20.6$ | 0.70 |
| 14 | $B_3$, $B_4$, $B_8$ | $235.2B_3 + 86.5B_4 - 269.0B_8 + 10.0$ | 0.67 |
| 15 | $B_2$, $B_3$, $B_4$, $B_8$ | $741.5B_2 - 180.3B_3 + 96.2B_4 - 384.3B_8 - 21.1$ | 0.82 |

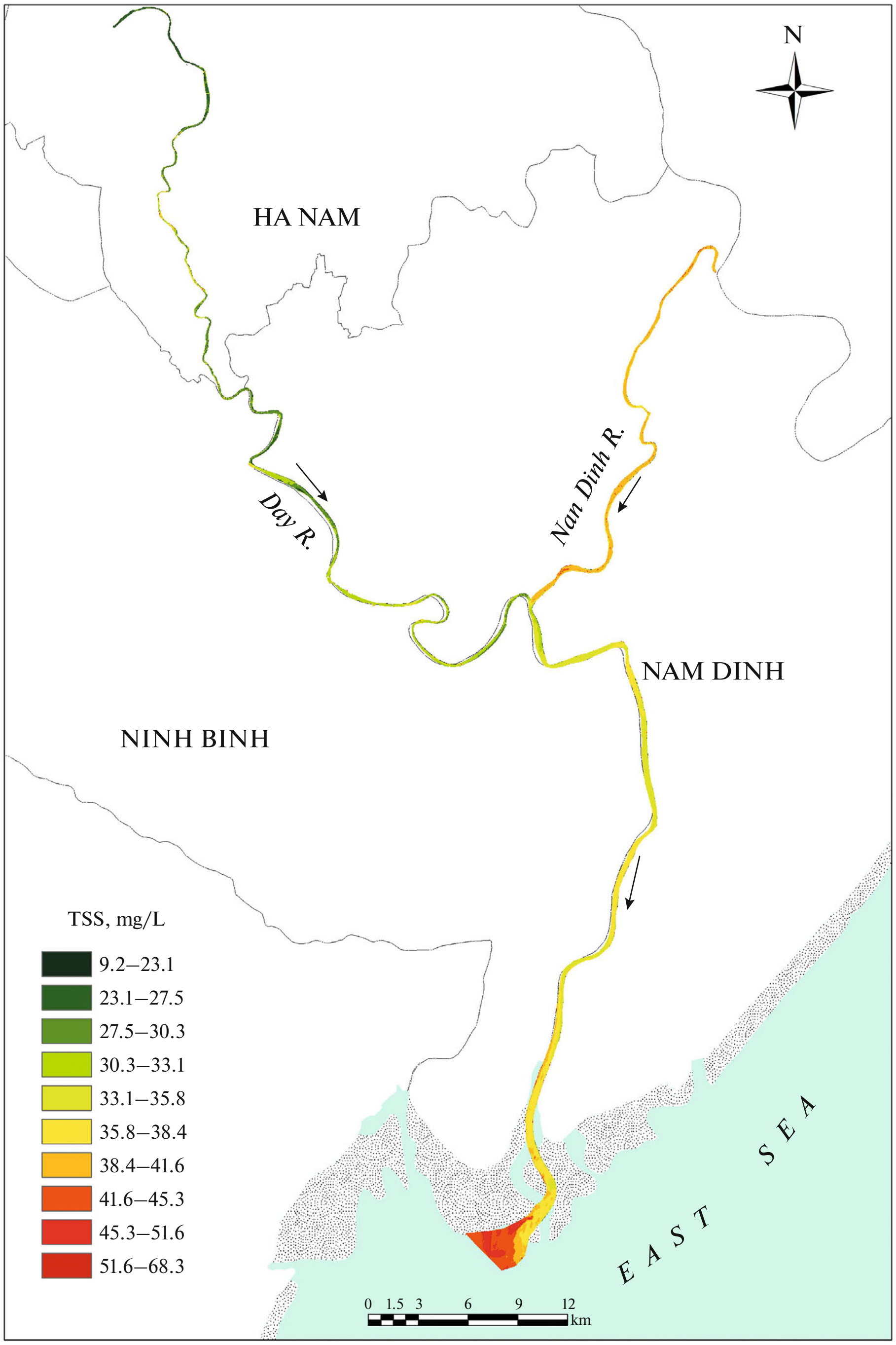


**Fig. 3.** Map of the distribution of suspended solids in the surface waters of the Đáy River, obtained using Sentinel 2 data.

**Table 4.** Content of suspension, determined from Sentinel 2 and ground-based data

| No. | Coordinates | | TSS concentration, mg/L | | Error, mg/L |
|---|---|---|---|---|---|
| | latitude | longitude | determination with remote sensing data | field results | |
| 3 | 20°33′14.0″ N | 105°53′41.0″ E | 23.9 | 22 | 1.9 |
| 8 | 20°31′46.3″ N | 105°54′44.9″ E | 25.0 | 26 | −1.0 |
| 15 | 20°19′41.7″ N | 105°56′08.4″ E | 26.0 | 24 | 2.0 |
| 20 | 20°15′06.4″ N | 106°01′59.1″ E | 30.9 | 30 | 0.9 |
| 28 | 20°07′23.0″ N | 106°09′44.0″ E | 31.4 | 33 | −1.6 |
| 31 | 20°03′22.0″ N | 106°07′53.0″ E | 42.1 | 40 | 2.1 |
| 35 | 19°58′56.8″ N | 106°05′54.4″ E | 39.1 | 36 | 3.1 |

The distribution of the amount of suspended matter in the surface waters of the Đáy River, calculated from Sentinel 2 data, is shown in Fig. 3. We can see that the concentration of suspended matter in the water varied from 9.2 to 68.3 mg/L, and there were few suspended solids in the upper reaches of the Đáy River. The concentration of suspended matter in the surface waters of the Đáy River reached high levels at the confluence of the Nam Dinh tributary, and tended to fall somewhat downstream. The amount of suspended matter the rose sharply in the lower reaches of the river and where it flowed into the sea.

According to national technical quality standards (Vietnam Ministry of Natural Resources and Environment, 2015), the quality of the river's water largely ranges from class $A_2$ (for water supply purposes using appropriate treatment technologies) to category $B_1$ (for watering, irrigation, or other purposes with similar water treatment requirements).

## CONCLUSIONS

Satellite images of MSI Sentinel 2 have very valuable characteristics, among which are a wide spectral range, short waits for reacquiring images on the same territory, high spatial resolution, and free provision to users. This allows Sentinel 2 data to be used to monitor river basins and estimate suspended solids in surface water for efficient water management. The accuracy of determining the content of suspended matter in the surface waters of the from Sentinel 2 satellite imagery was quite high. The coefficient of determination in $R^2$ regression equations reached a value of 0.82, while the errors in estimating the suspension in water using space-based data was no greater than 3.1 mg/L.

Analysis of our results showed that the water of the Đáy River in Ha Nam, Nam Dinh, and Ninh Binh provinces had a low suspended matter content (according to the QCVN08-MT classification: 2015/BTNMT from $A_2$ to $B_1$). The content of suspended solids in river water grew downstream of the river and reached its maximum at the river mouth. High concentrations of suspended matter were found at the confluence of the Đáy River and such smaller rivers as the Boi and Nam Dinh.

The methodology developed in this work can be useful for managers at different levels, ecologists, and other specialists for timely implementation of preventive measures in order to reduce pollution in the surface waters of river basins.

## ACKNOWLEDGMENTS

The authors thank Dr. Trinh Thi Tham, Hanoi Institute of Natural Resources and the Environment (Vietnam), for providing data needed to complete this study.

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