http://doi.org/10.29227/IM-2021-02-27 Received: 05 Jun 2021, Accepted: 05 Sep 2021, Published: 10 Nov 2021

Estimation of Suspended Sediment Concentration in Downstream of the Ba River Basin using Remote Sensing Images

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Abstract. Assessing the tendency of suspended sediment concentration (SSC) in the river watersheds enables a better understanding of the hydromorphological properties of its basins and the associated processes. In addition, analyzing this trend is essential to address several important issues such as erosion, water pollution, human health risks, etc. Therefore, it is critical to determine a proper method to quantify spatio-temporal variability in SSC. In recent years, remote sensing and GIS technologies are being widely applied to support scientists, researchers, and environmental resource investigators to quickly and synchronously capture information on a large scale. The combination of remote sensing and GIS data will become the reliable and timely updated data source for the managers, researchers on many fields. There are several tools, software, algorithms being used in extracting information from satellites and support for the analysis, image interpretation, data collection. The information from satellite images related to water resources includes vegetational cover, flooding events on a large scale, rain forecast, population distribution, forest fire, landslide movements, sedimentation, etc., and especially information on water quality, sediment concentration. This paper presents the initial result from LANDSAT satellite image interpretation to investigate the amount of sediment carried downstream of the Ba river basin.

Keywords: Remote sensing image, Suspended sediment concentration, Downstream of the Ba river basin

1. Introduction

Suspended sediment, representing most of the total amount of sediment transported downstream and being easier to monitor than other components [1], is commonly used to estimate sediment loads within a stream [2]. Suspended sediment is a water quality constituent of particular concern to many rivers, lakes because this parameter increases turbidity and can influence the transport of particle-bound contaminants such as nutrients, organic compounds, pesticides, and trace metals [3]. Timely information on total suspended matter plays an important in assessing the effects of a wide range of issues caused by poor water quality. In order to study changes in the sediment-related environment, such as alterations of river morphology, degradation of water quality, or negative influences on aquatic ecology, it is indispensable to accurately supervise the transport and discharge of suspended matter in rivers [4, 5, 6]. In fact, many rivers in the world have either not been gauged or their sediment data are not readily available. Therefore, estimating the sediment load in turbid systems is an important aspect at the catchment level [7]. Unfortunately, the acquisition of reliable suspended sediment concentration data at the necessary spatial and temporal resolution can often be prohibitively time-consuming and expensive in large rivers.

Several methods have been mentioned to predict suspended sediment concentration, ranging from field measurement, basic sediment rating curves [4, 7, 8, 9, 10], remote sensing [11, 12, 13, 14] to more complex models such as support vector regressions [15, 16], artificial neural networks, regression trees and model trees [17, 18]. In the field measurement method, observations are typically collected using cumbersome in situ samplers deployed along bridges, boats, or cableways for monitoring SSC and local sediment transport in large fluvial systems [19]. The main advantage of on-site sampling is that it can provide accurate measurements of suspended sediments within a given location at a given time. However, this measurement is constrained by severely limited spatial and temporal samplings of suspended sediment due to the high cost and time-consuming methods currently used for in-situ observation, especially in a large area [13]. Furthermore, employing datasets gathered by in situ monitoring devices or stations for local analysis and large-scale sediment quantification can lead to high uncertainties and potential error [20]. The complex models are suitable to the complexity of the sediment dynamics sometimes requires more sophisticated approaches to explain most of the variability in SSC [21].

Alternatively, a remote sensing approach may provide an appreciated tool for quantifying SSC in river systems. As Marrinez et al. (2015) indicated that, remote sensing is an efficient tool for hydrological monitoring in large rivers, because it allows relate the color of the water to its content using satellite [22].

With its advantages, satellite images are used in many studies on the distribution of factors on the surface. Besides using remote sensing imageries for studing the surface temperature distribution [23], many studies have used this technology to predict the SSC distribution. Remote sensing tools can provide the images with a high spatial and temporal resolution to estimate surface suspended sediment concentration in large rivers that are not available from traditional in situ measurements [24, 25]. Over the last several decades, satellite image has been used to retrieve SSC data because it has wide spatial coverage and high temporal repeatability, and various visible and NIR bands have been proposed as the SSC indicators [13]. The sensors have been used to analyze water quality parameters including suspended sediment. Based on the relationship between SSC and spectral reflectance, prediction SSC has been implemented using a range of statistical modeling techniques and satellite data. Therefore, a remote sensing approach has been used to determine the SSC, through models and algorithms showing potential at regional, multi-temporal and synaptic levels. Costs involved in this procedure are considerably lower than those of in situ samplings and laboratory analysis [26].

Previously, models associating SSC and spectral reflectance using different multispectral satellite sensors have been generated by many scientists. They utilized from coarse spatial resolution such as MODIS and MERIS [27, 28] to relatively finer spatial resolution, for example, the Landsat series [29, 30, 31, 32]. There are few studies mentioned on estimating SSC in rivers utilizing MODIS satellite images because of the coarse spatial resolution of the data comparing to the size of the rivers [33]. With the launch of the Landsat 8 Satellite, in 2013, this sensor has a high potential for monitoring the aquatic environment and so the possibilities of studies in hydrology fields have expanded. The Landsat 8 data are already being used to predict turbidity and sediment concentration [34, 35, 36. 37]. Our literature review has revealed that SSC is highly correlated with the first four bands of the Landsat sensors [38] and the use of an appropriate single band from the sensor series can provide an accurate estimate of SSC [39]. Gholizadeh et al. (2016) indicated that sensors from the Landsat satellite series (TM, ETM+, OLI) are the most regularly used remote sensing platforms to predict SSC [40]. Results from previous studies also have proven Landsat 8 as a proper satellite asset for a robust estimation of SSC.

Besides on the main rivers, suspended sediment formed in the fields and canals is mostly fine-grained. This material is capable of providing a good source of nutrients for the ecosystem. The distribution of alluvial particles fluctuates greatly according to the season and different locations in the basin. Furthermore, the monitoring data in a concentration of suspended sediment is often very little, so it is not enough to assess the evolution and change trend of sediment in the basin. Therefore, the interpretation of remote sensing images to estimate the SSC partly meets the demand for SSC data as well as provide the initial scientific basis for the assessment of the SSC in the river basin for developing agricultural and forestry field.

In order to map the SSC, it is necessary to process, analyze, and interpret the satellite image, especially focus on image editing, image interpretation, publishing documents from images. Up to now, the research on the application of remote sensing in predicting the SSC has continued to develop by analyzing images and the measured spectrum or images and field measurements. This study aimed to estimate SSC in downstream of the Ba river basin from the use of Landsat satellite imagery and the obtained results are validated by field documents at different times and locations.

2. Research area

The Ba River is one of the major river systems in the Central Highlands and Central Coast area with a basin natural area of 1,413,204 ha (including the Ban Thach branch). The geographical position of the basin is about 12°55′ to 14°38′ north latitude and 108°00′ to 109°55′ east longitude on the northern borders of the Sesan river basin and the Tra Khuc river, the southern borders of the Cai river basin and the Srepok river, and the eastern borders of the basin of Kon river, the Ky Lo river, and the East sea. Ba river basin is located in the area of both Western Truong Son and Eastern Truong Son, accounting for 4.3% of the country's area, belonging to three provinces of Central Highlands, namely Gia Lai, Dak Lak, Phu Yen, and a very small part of Kon Tum [41]. The Ba River has a drainage area of 14x103 km^2, and provides $1x10^6$ tons of suspended sedimentary material annually into the East Sea [42].

The downstream area of the Ba river basin has mountain ranges with an elevation of 200 - 500m, covering all three north, west, and south directions. The estuary and coastal areas have elevations ranging from 0.5 to 2 m, with long stretches of sand dunes along the coast. The average rainfall in the basin is about 1730 mm with a flow modulus of 23.6 $l/s/km^2$, annually the Ba River flows into the East Sea with more than 10 billion m^3 of water. The sediment in the river is generated by the interaction between the water flow and the basin surface. There are many factors affecting SSC in the river such as the slope of the basin, runoff, topography, buffer surface, etc. But the flow factor has the greatest influence on the amount of sediment in the river [41].

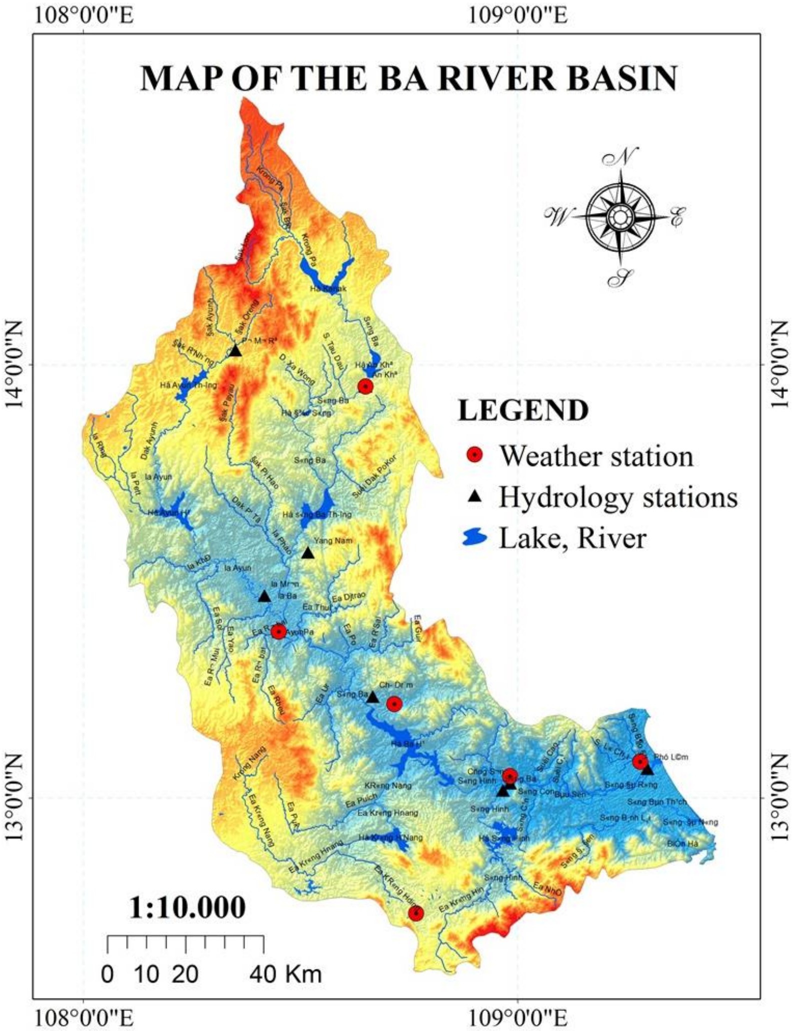

Fig. 1. Ba river basin.

3. Methodology and Data

The Landsat 8 images have been analyzed in the present study due to its wide range of spatial and temporal data available for the Ba river basin, and it has an acceptable spatial resolution of 30 m x 30 m for mapping large rivers. Data obtained from all four Landsat satellites were used to study the Ba river basin including both Landsat 4 and Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Mapper Plus (ETM+), and Landsat 8 Operational Land Imager (OLI), for the upstream and midstream area with Path = 123, Row = 50, downstream area with Path = 123, Row = 51. Imagery with adequate meteorological conditions was searched from various dates with no clouds present (0% of clouds). Each satellite crosses every point on Earth once every 16 days with 8 days offset data acquisition, while two Landsat satellites were in operation [43] (Sutari et al., 2020). Landsat Level-1 surface-reflectance data products were downloaded from the http://glovis.usgs.gov/ website from 1991 to 2016 for the study area to create the Landsat database. All scenes were projected into UTM Zone 49/WGS 84 and radiometrically and geometrically corrected to account for differences in sun and sensor angles as well as atmospheric conditions.

Atmospheric corrections: The purpose of atmospheric correction is to determine true surface reflectance values by removing atmospheric influences from satellite images. The atmospheric conditions influence the radiometric response of the acquired images [44]. These impacts can be eliminated by Radiometric and atmospheric corrections and converted digital levels in physical and biophysical variables. In the present study, photographs were adjusted using physical models of radiative transference, usually based on a series of standard atmospheres [45]. There are many methods to correct atmospheric effects with Landsat-8 images such as using commercial software such as FLAASH of Envi, ATCOR of ERDAS or ACOR, 6S, etc. In this study, ACOLITE tool was used to adjust atmospheric effects. This tool a very popular applied to the studies of the aquatic environment.

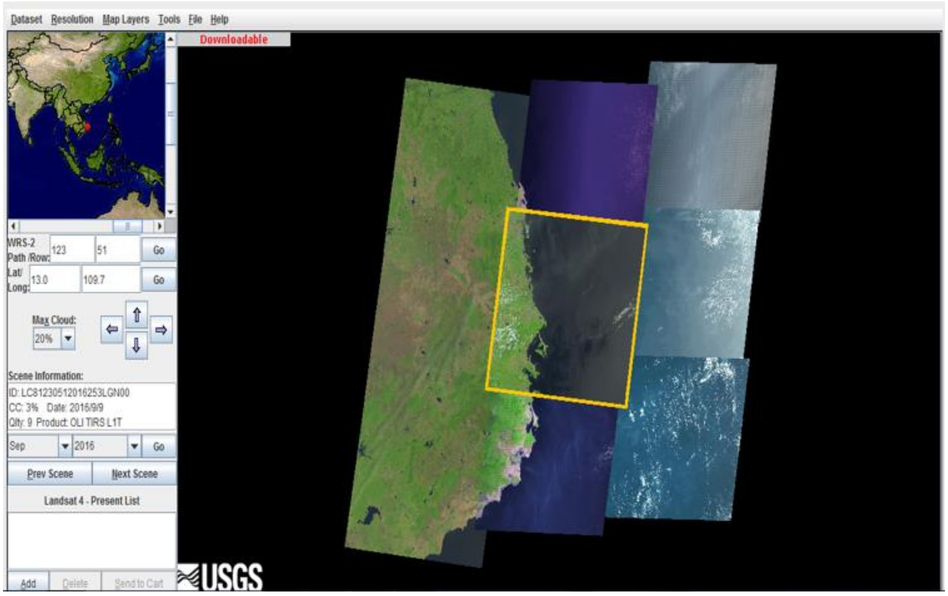

Fig. 2. Landsat satellite data of downstream of the Ba river basin.

Image processing: After the atmospheric and radiometric corrections, the image was cut according to the study area. The salt and pepper error was adjusted by applying a media filter with a 3 × 3 kernel. The Normalized Difference Vegetation Index (NDVI) is employed to reach the goal of isolating water and non-water features. This index was used to separate the reflectance of the green portion of vegetation from any other surface. However, it was proven useful to detect water surfaces [46]

Features related to water resources that can be collected on remote sensing image data include the length of rivers and streams, the width of riverbeds, catchment slope, branching coefficient, meandering coefficient, the roughness of the buffer surface, the speed of the flow, etc. The relationship between them is expressed by the following equation [47]:

$$V = \frac{R^{2/3} S^{1/2}}{n};\ R = \frac{A}{P} \quad (1)$$

where:

A- Cross-sectional area of rivers and streams (m^2); P - Wetted perimeter (m); S – The slope of energy grade line; n – The coefficient of the roughness of the buffer surface. V - Average flow rate (m/s); In the real case, the speed V can be calculated based on the analysis of sample images with moving objects in the image.

In addition, it is necessary to determine the spectral coefficient for the Landsat image with bands 5, 6, 7 to calculate the amount of solid flow for a basin according to the following formula [48,49]:

$$X = \frac{N_4}{\sum_{1-4}^{6} N_i};\ Y = \frac{N_5}{\sum_{1-4}^{6} N_i} \quad (2)$$

where:

N_i is the radiation coefficient on the i-th band; X and Y are values on the colormap axes, and X' = X + ΔX, Y' = Y + ΔY; ΔX and ΔY are correction factors due to the atmosphere in each region on the colormap.

The amount of sediment for each basin is determined by the following formula [48,49]::

$$S_{YI} = EA*V*D*100/A \quad (3)$$

where

EA: Erosion coefficient of the basin; A: Basin area; V: Flow rate; D: The distribution ratio of the river

The total amount of turbidity can be determined by the following formula [48,49]::

http://doi.org/10.29227/IM-2021-02-27 Received: 05 Jun 2021, Accepted: 05 Sep 2021, Published: 10 Nov 2021

$$T_{ss} = a + b(Z_6)^{1/2} + C(Z_7)^2 + d(Z_5)^{1/3} \quad (4)$$

where:

T_{ss}: Total Turbidity (mg/l)

$Z_5 = X_5/ 2.8132$; $Z_6 = X_6/2.7002$; $Z_7 = (X_7 – 0.5524)/ 0.4265$

X_5: Average value on band 5; X_6: Average over band 6; X_7: Average over band 7

a = 399.850; b = 135.787; c = -0.0115 and d = 321.630 (empirical coefficient)

4. Results and Validation

The study uses Landsat 8 image data to analyze the sediment flow for the Ba River downstream area with the boundary of the downstream area calculated from behind Ba Ha reservoir towards the estuary. Figure 3 shows the study area (downstream of the Ba River) on a DEM map with a resolution of 30x30 m including a river network system and hydro-meteorological stations in the basin. Color composite used in this paper are band 6, band 5, band 2 as red, green, blue from Landsat 8 imagery data. A natural color map is obtained that reflects the current state of the Ba River's buffer surface, in which the green color represents the vegetation cover, the red color represents the soil layer and blue color represents water areas such as rivers, streams, reservoirs, hydroelectric dams, lagoons, etc. (Fig. 4).

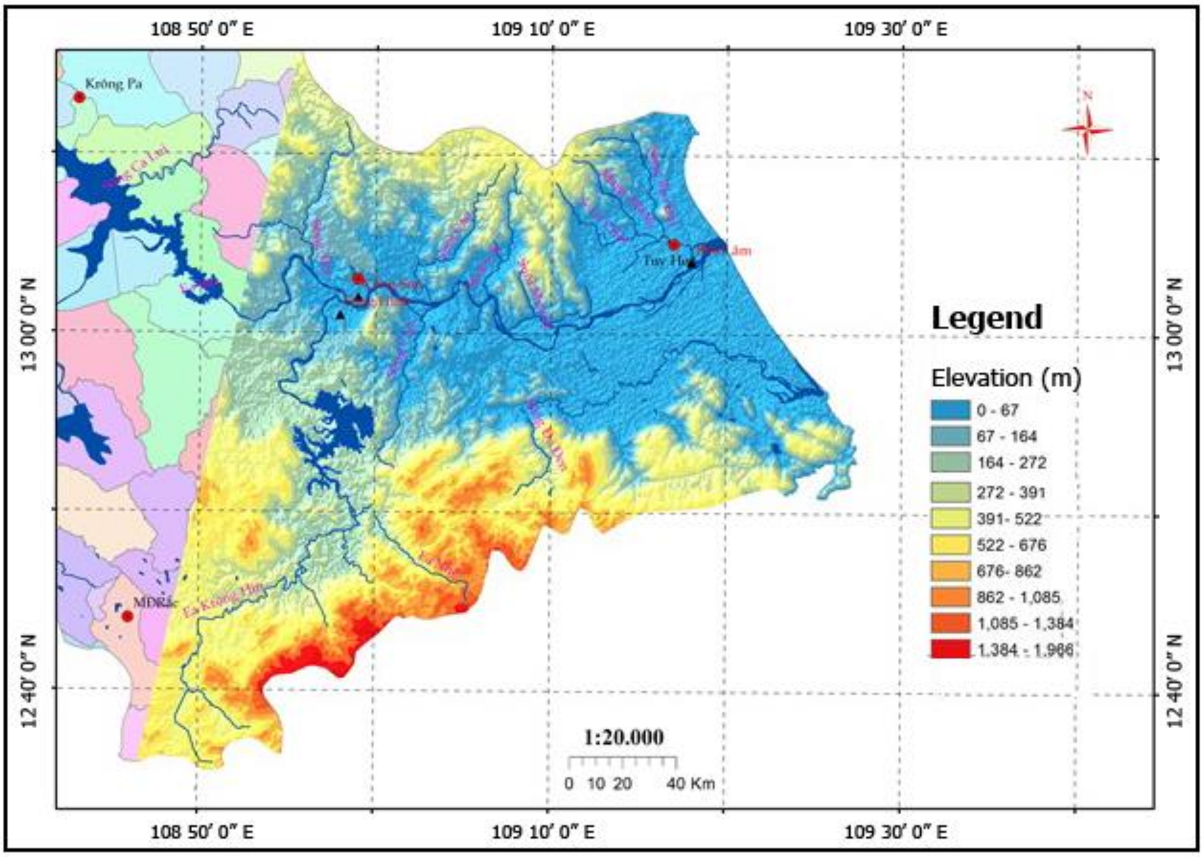

Fig. 3. Downstream of the Ba River basin on a DEM map.

Using Image Analysis, Classification tools, and sediment survey data at some locations in the Ba River downstream, remote sensing image interpretation and obtained results were shown in Figures 5 and 6. From Figure 6, it can be seen that the SSC in downstream of the Ba river is quite evenly distributed, areas with large SSC are mainly concentrated in rivers and lakes and fluctuate in the range of 10 mg/L - 15 mg/ L. The area spread throughout the basin has SSC ranging from 2 mg/L to 5 mg/L (76% of the downstream area). Thus, downstream area of the Ba river, the potential for SSC is low compared to other basins in our country.

The study uses data from the Cung Son hydrological station (about 12 km downstream from Ba Ha lake and 45 km from the Da Dien estuary) to verify the estimated results. According to the South Central regional hydrometeological center, measurement data at Cung Son station on the main Ba river, the average amount of the SSC in many years varies from 70 - 180 g/m^3. The maximum amount of sediment can reach 1730 g/m^3, while the lowest SSC is in the dry season months and usually below 50g/m^3, even some days this value is only 0 g/m^3. The obtained results show that the sediment concentration in the area of Cung Son station is estimated in the range of 10-15 mg/L, much smaller than the actual measured average SSC value of many years. The reason is that the data used to estimate the SSC in the study area is collected in the dry season when the flow in the river is small and the amount of sediment transported is also much smaller.

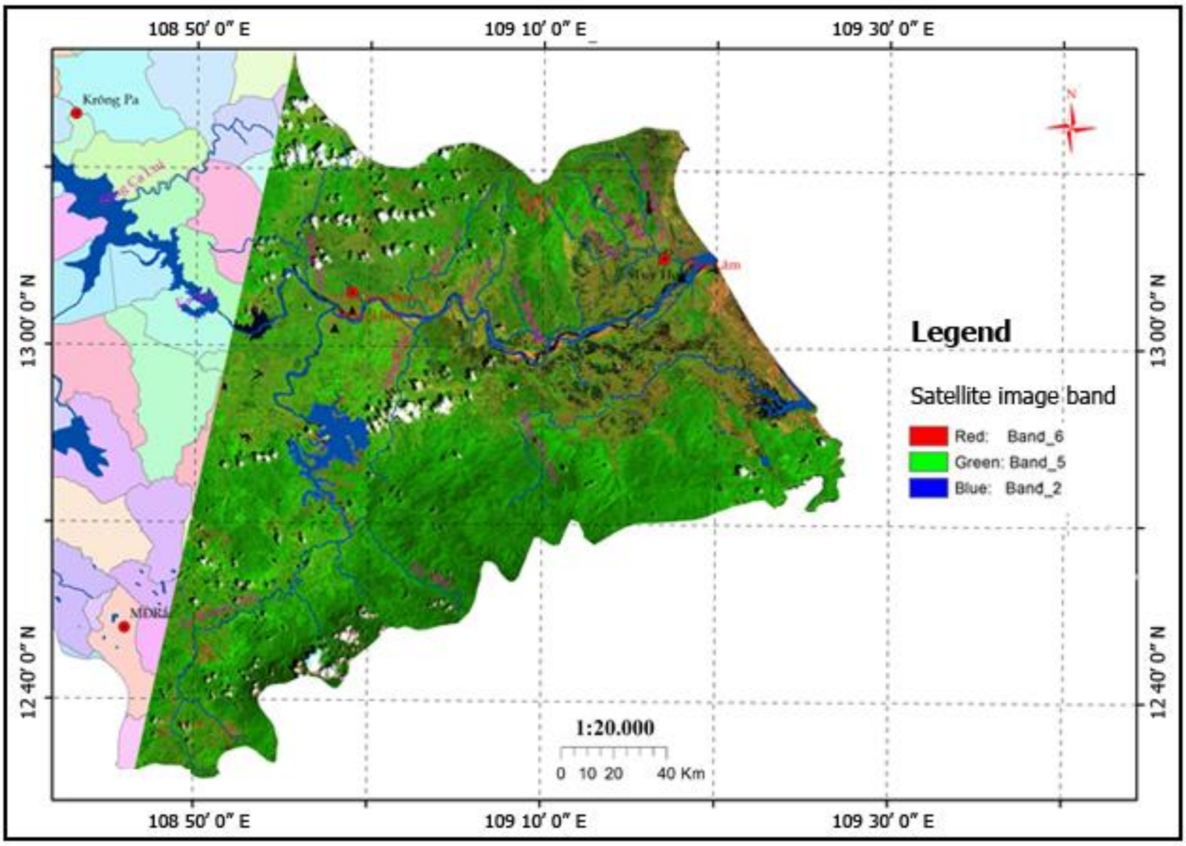

Fig. 4. Current map of buffer surface in the Ba river basin.

In addition, the remote sensing image data for this study were taken at the time after the operation of Ba Ha reservoir. Research results of Giang et al. (2017) shows that the Ba Ha reservoir has a significant impact on the SSC in the Ba river basin [50]. In particular, when considering the total amount of sediment for the whole year at Cung Son hydrological station, we can clearly see the shortage of sediment in the period after Ba Ha reservoir is operational. Therefore, with the SSC in Cung Son stattion of 10-15 mg/L, it is consistent with the law of sediment change of the downstream under the impact of the reservoir. It is very difficult to determine SSC because the alluvium of the study area has fine particles and precipitates, so this result can be used for calibration service of sediment transport models. Thus, obtained results are objective and can be acceptable. This proves that the method used in the study is reliable and this allows the usage of image analysis to calculate the SSC in the future. This is a useful data source to supplement data for studies and applications in cases where actual measured data are limited.

Besides the obtained results, using satellite images to estimate SSC has some limitations. Because optical satellites are completely dependent on weather conditions, it is difficult to obtain satellite images with optical cloud conditions corresponding to the time of field sampling for verification. The study area is often cloudy, while clouds are one of the factors that greatly hinder the interpretation of satellite images since it will cover observed objects, create shadows on the objects' surface affecting the quality of interpretation causing difficulty in evaluating the spatial distribution of the SSC.

In addition, the field measurement depends on the satellite transit time, so the survey route must be designed so that the sampling time coincides with the time of the Landsat-8 satellite pass (approximately 10h17) [51]. Besides, according to Nguyen Khac Thoi et al. (2011), light intensity will decrease exponentially with increasing depth when entering the water. Light that is weakened to a certain depth will have no reflection and is completely absorbed in the water. The degree of attenuation is different with wavelengths of electromagnetic radiation, especially in the visible spectral bands, the higher depths, the worse the reflection [52]. Therefore, this is one of the factors affecting the accuracy as well as the difficulty of image interpretation to estimate SSC for the study area.

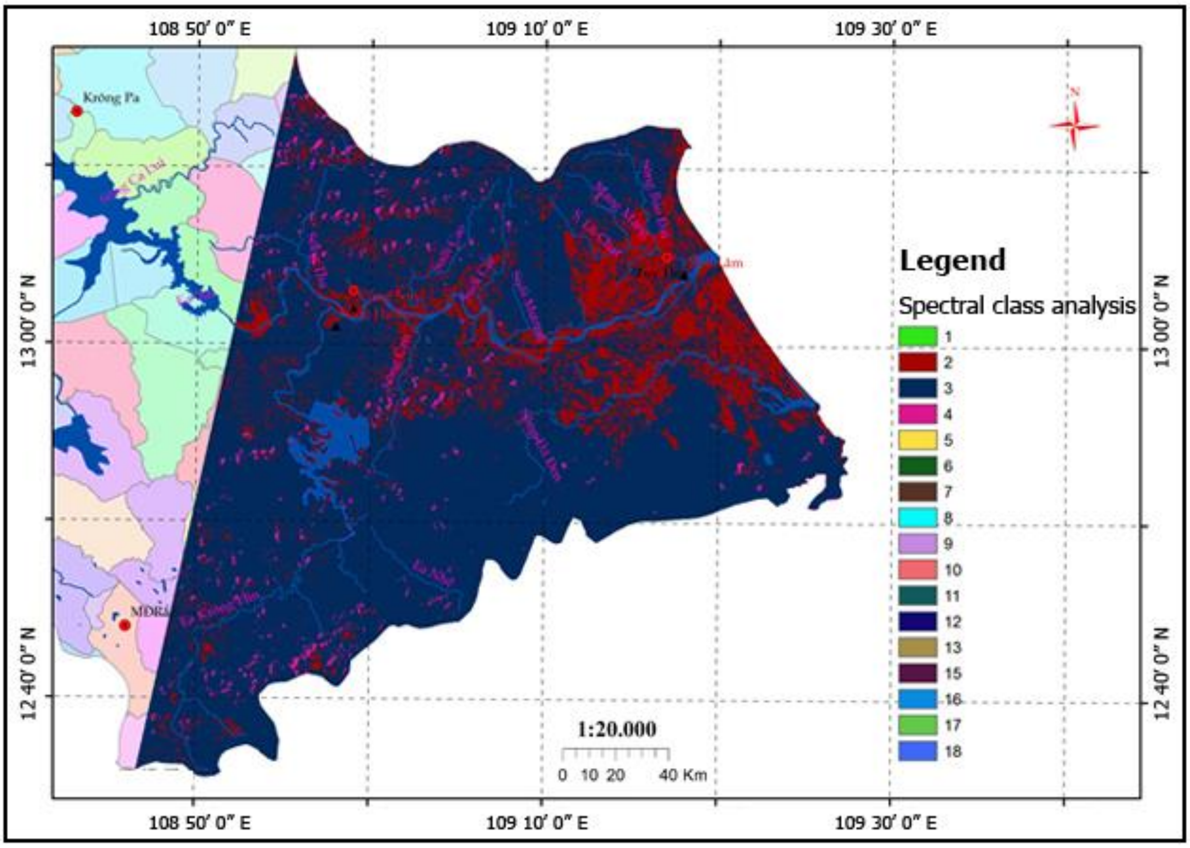

Fig. 5. Spectral analysis from Landsat image of the Ba river basin.

5. Conclusion

The results of this investigation show that it is feasible to use Landsat image data for quantifying, assessing, and mapping suspended sediment concentration of an Ba river basin. Moreover, the researches show that the Landsat 8- derived green–red band ratio is minimally susceptible to uncertainties in the atmospheric correction allowing for its utility for river water management. Map of SSC distribution in the Ba river basin revealed that the SSC is highly related to the seasonal variation and the area with high SSC is mainly concentrated in the lake and river. The results of SSC estimation for the whole study area accurately reflect the trend of SSC fluctuations over time in the year compared to the measured data as well as consistent with the influence of river hydrodynamic factors in the study area.

Through careful analysis and interpretation of satellite images, it is shown that we can study suspended sediment changes by approaches using remote sensing image data. Nowadays there are many websites that provide free quality satellite images with a resolution of about 30 m. Therefore, it is necessary to focus in this research direction to obtain a SSC database in space and time, ensuring a scientific basis for the assessment and analysis of the impact of the upstream dam, the impact of the internal area of the embankment system, etc. on the SSC in the basin. The combination of satellite image interpretation and hydrological measurement data allows us to calculate the amount of the SSC and sediment spilled into the field. The research results can be used to develop a plan for the transmission of sediment to clean the fields and support the development of agriculture more effectively.

Due to the limitation of actual measured data at different locations, it is necessary to collect more measured data at different locations to increase accuracy. In addition, it is necessary to use a combination of satellite images with different spatial and temporal resolution levels to support better assessment of the SSC distribution as well as limit the influence of clouds on the research results

http://doi.org/10.29227/IM-2021-02-27 Received: 05 Jun 2021, Accepted: 05 Sep 2021, Published: 10 Nov 2021

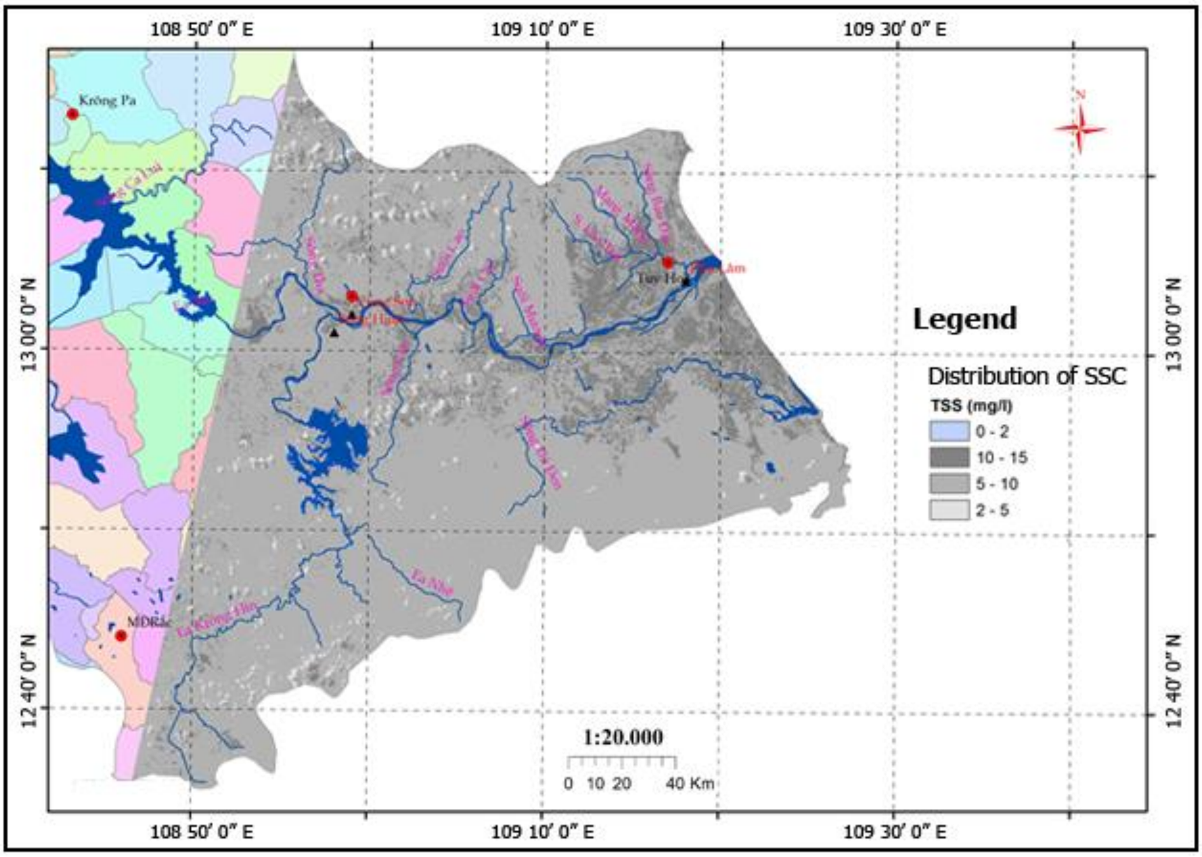

Fig. 6. Distribution of SSC in the Ba river basin from Landsat image.

6. Acknowledgements

The authors are grateful to South Central regional hydrometeological center, Vietnam for providing data to complete this paper. In addition, the author thanks unnamed reviewers for their valuable comments which helped us to improve the quality of the manuscript.

The paper was presented during the 6th VIET - POL International Conference on Scientific-Research Cooperation between Vietnam and Poland, 10-14.11.2021, HUMG, Hanoi, Vietnam.

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