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MAPPING OF THE ALGAE DISTRIBUTION TO SUPPORT WATER QUALITY MANAGEMENT IN THE DAU TIENG RESERVOIR

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Abstract: In the last two decades, the development of satellite technology has made it easier and more convenient to apply remote sensing in warning and solving environmental problems, especially the tracking, monitoring, and evaluation of environmental objects. Algae blooms are one of the top environmental issues of concern today. The blooms cause many harmful effects on the water environment and ecosystems in the area, such as reducing dissolved oxygen levels and producing harmful toxins, causing aquatic organisms to lack oxygen and be poisoned and dead. This study presents the research results in monitoring and calculating the concentration of algae in the Dau Tieng Reservoir by remote sensing. By constructing a regression function between monitoring data and qualitative algorithms from Landsat image spectrum reflection, the study conducted quantification and mapping of the distribution of algae concentration in the Dau Tieng Reservoir area. The calculation results show that the qualitative algorithm 3BDA(3) from the spectral bands in the GREEN, RED, and near-infrared NIR wavelength bands shows a reasonable degree of correlation with the monitoring data. Since then, the author has mapped the distribution of algae concentration and the current status of blooming algae on the reservoir at 3-time points. The study's results show the feasibility of applying remote sensing technology in monitoring, evaluating, and analyzing the concentration of algae in Dau Tieng Reservoir. The calculation results are an essential source of advice in managing reservoir water quality to prevent and minimize environmental and ecosystem damage in the area local water bodies.

Keywords: algal blooms; ratio band; regression analysis; remote sensing; reservoir

1. INTRODUCTION

Under the impact of global industrialization and urbanization trends, recent decades have witnessed alarmingly increased greenhouse gas emissions into the atmosphere (IPCC, 2013). These gases interfere with the process of reflecting solar radiation into space, causing the temperature of the Earth to rise (Melillo et al., 2014; Watson et al., 2015). Global warming increases the temperature in aquatic areas, a highly favourable condition for developing algae species (Phlips et al., 2020; Watson et al., 2015). In addition, the booming world population and the development of urban centres and industrial parks are sources of waste in the water environment. These wastes have an extremely high nutrient content, enriching aquatic nutrient areas, a nutrient source that helps algae thrive (Watson et al., 2015). Not to mention the use of chemical fertilizers in agriculture, which contains many nutritional ingredients such as Nitrogen, Phosphorus compounds, etc., heavy rains often wash away this amount of fertilizer and pour it into nearby aquifers, causing eutrophication and creating favourable conditions for algal blooms (Mateo-Sagasta et al., 2017).

The algal blooms are defined when the algal density reaches 100,000 cells/mL or even lower level provided that it can cause negative impacts on human health and organisms (WHO, 2003). This phenomenon has severe impacts on the habitats of domestic species. They deplete the water's oxygen source, seriously depriving aquatic organisms of oxygen sources (Watson et al., 2015). Besides, some algae can produce toxins, typically cyanobacteria (blue algae). These toxins infect species and lead to death (Trung et al., 2018; Watson et al., 2015). Algal blooms in marine environment also adversely affect the survival and development of benthic organisms and coral reefs, which are living and breeding habitats for many marine species (Andrew et al., 2010). Algae also cause an enormous cost to humans through the mass fish, bivalve and shrimp kill in aquacultures. Algae toxins secreted into the aquatic environment also affect ecological health, and human beings via domestic use, bathing and water sport activities (Watson et al., 2015). The severe harmfulness caused by the algal blooms has placed an urgent requirement on monitoring and supervising this phenomenon to issue prompt warnings. However, monitoring the concentration of algae in a large area using traditional measuring methods is extremely difficult, a lot of time requirement and expensive.

The remote sensing method allows monitoring of the ground surface by pixel image elements covering a study area, combining image processing techniques to detect surface objects exhibiting dominant advantages. In the world, the application of remote sensing technology, tracking the evolution of algae by satellite images is the method often used by researchers in more than two recent decades, such as the study using image band combination (GREEN+NIR)/RED for Landsat-7 images to analyze the concentration of algae in a section of Ohio River, USA (Bee, 2009); the study compared two-band algorithm (2BDA), three-band algorithm (3BDA) and Normalized Difference Chlorophyll Index (NDCI) (Augusto-Silva et al., 2014); the study comparing the accuracy of algal bloom analysis between radar images and satellite remote sensing images (Wang et al., 2015); the study of the effectiveness of algorithms of WorldView, Sentinel-2, Landsat-8, and Meris/OLCI satellite images (Richard et al., 2018); the study comparing the effectiveness of 2BDA, 3BDA, and NDCI on different satellite images (Buma & Lee, 2020) or NCDI difference study on Sentinel-2 and Sentinel-3 images (Caballero et al., 2020). The research results indicate that, between the reflection spectrum value and the actual value, there is a linear relationship at a fairly high level (with R^2> 0.7). Some studies on algae were also carried out in Vietnam, such as the study on the water quality of the Day estuary (Phi et al., 2014) and the water quality of Ke Go Lake (Son et al., 2019), including Chlorophyll-a parameters; the study on monitoring the concentration of algae in Tri An Reservoir (Hao-Quang et al., 2019). In general, the application of remote sensing technology in assessing algae blooming has been widely studied and developed in the world, but there are still limited studies in Vietnam. Therefore, the paper is made to study and apply more remote sensing technology in assessing and monitoring the phenomenon of algal blooms.

2. STUDY AREA

Dau Tieng Reservoir is located upstream of the Saigon River in three provinces: Tay Ninh, Binh Phuoc, and Binh Duong. The reservoir has geographic coordinates from 11°29'07" to 11°36'15" North latitude and from 106°10'49' 'to 106°29'07" East longitude, 25 km Northeast of Tay Ninh town and 70 km northeast of Ho Chi Minh City (Figure 1). Started in 1979 and completed in 1985, Dau Tieng Reservoir is the largest irrigation project in Vietnam, with an effective capacity of about 1.45 - 1.5 billion m^3, a water surface area of 27,000 hectares, including 5,000 hectares of semi-flood land, capable of irrigating 175,000 hectares of cultivated land in Tay Ninh, Ho Chi Minh City, and Long An Provinces. The water level ranges from 17 to 24 m (Tam, 2007). Dau Tieng Reservoir is a multi-functional reservoir for flood prevention, domestic water supply, irrigation, salt washing, improving the quality of Saigon River water, and aquaculture (Dao et al., 2013).

The reservoir is located in a tropical monsoon climate, divided into two clear seasons: the dry season from December to the end of April and the rainy season from May to the end of November. The climate in the reservoir area is hot, humid, and temperate all year round because it is located deep in the continent, so it is less affected by storms and other adverse factors. The average annual temperature is around 27.4°C, and the average annual humidity is around 70 - 80%. The amount of light is abundant all year round; on average, there are up to 6 hours of sunshine per day (Tam, 2007). The average annual rainfall is 1,800 - 2,200 mm, mainly in the rainy season. About 70 - 80% of the total flow in the year is concentrated in the 3-5 months of the rainy season, whereas the remaining flow is concentrated in the dry season. Module annual flow is from 20 - 25 $l/s\text{-}km^2$ and lower in the dry season, which is a favourable growth condition for algae species that prefer a low-turbulence water environment, warm temperatures, and abundant light to grow (Watson et al., 2015). In addition, the current water quality at Dau Tieng Reservoir is declining and showing signs of enrichment due to being affected by the waste source of sand mining activities, aquaculture, farming on the shore, and the area of reclamation and cattle breeding (Dao et al., 2013). It further facilitates the growth of algae species.

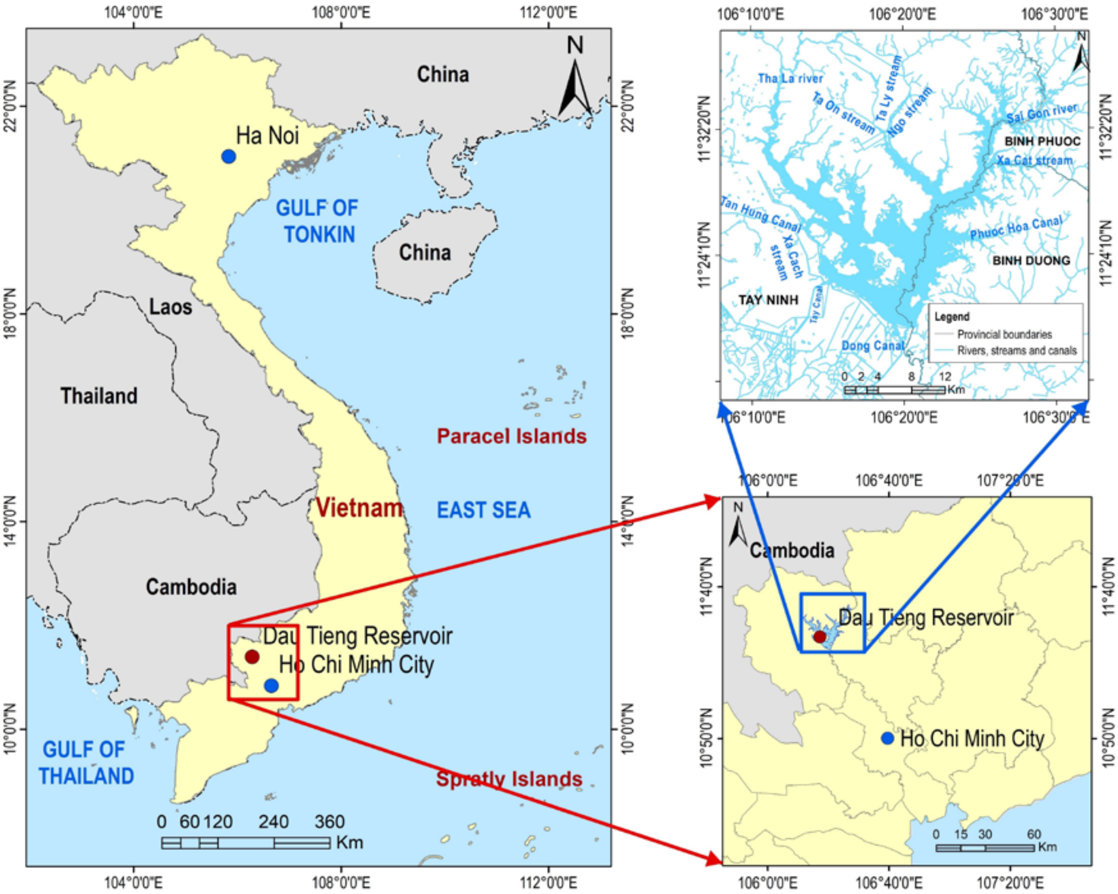


Figure 1. Geographical location of Dau Tieng Reservoir in the south of Vietnam

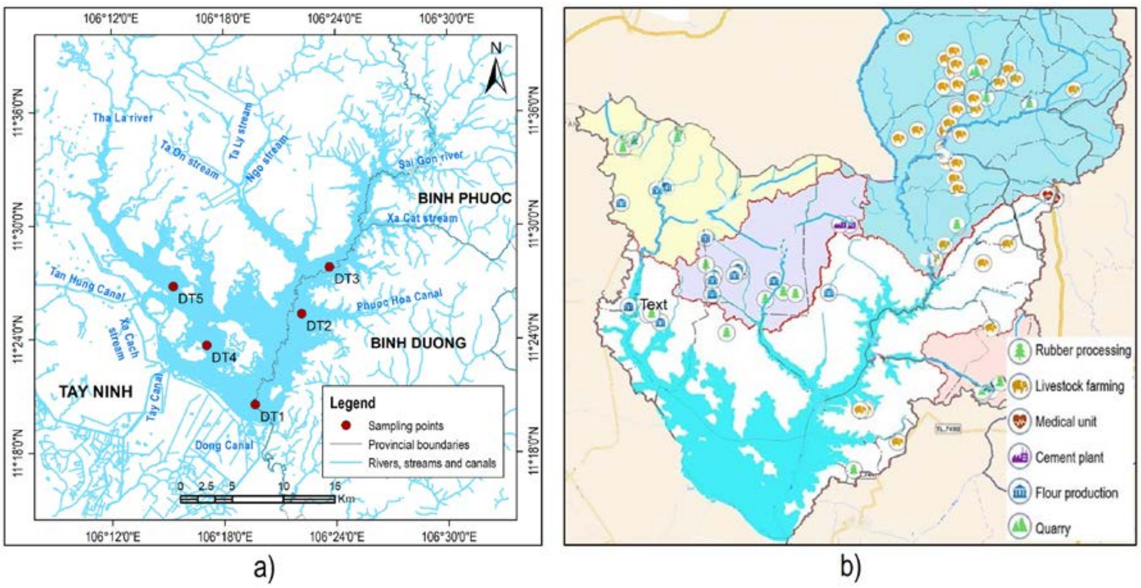


Figure 2. a) Location of sample monitoring points on Dau Tieng Reservoir, b) Production activities in Dau Tieng reservoir basin refer from DT-PH IEIC (https://bwe.com.vn/hodautieng/)

3. DATA AND METHOD

3.1 Data

Our research data were of 2 types: algal data (cyanobacteria) and satellite data. The cyanobacterial sampling, enumeration, and biomass estimation were described in detail by Pham et al., (2017). The monitoring on cyanobacteria were implemented at five sampling sites in the Dau Tieng Reservoir from March 2012 - February 2013 as shown in Figure 2. Their coordinates were presented in Table 1. The observation and quantification revealed that three main groups or orders of cyanobacteria, including Chroococcales, Nostocales, and Oscillatoriales, were commonly presented in the reservoir. Among the 16 cyanobacterial genera and 42 cyanobacterial species, the species of *Microcystis* (7 species), *Cylindrospermopsis* (1 species), and *Dolichospermum* (9 species) were able to produce toxins and could fast proliferate to form blooms in favorable conditions such as rich nutrients, and high temperature. The cyanobacteria biomass varied from 0.55 to 41.72 mg fresh weight/liter, covering the biomass range of a cyanobacterial bloom. The high cyanobacteria biomass could represent algal biomass in the water body because the biomass of other algal groups should be much lower upon the mass development of cyanobacteria. In this study, we focused on cyanobacteria data collection. Therefore, in most of the article, we use the word "algae" to generally refer to the reservoir's condition, to detect and warn its water quality.

The high biomass of cyanobacteria and the presence of the cyanobacterial toxin (microcystin) in the Dau Tieng Reservoir (Pham et al., 2017) possessed serious health risks to the health of the local aquatic ecosystem and human communities who directly and indirectly used the surface water from the reservoir for domestic purposes day by day.

Table 1: Coordinates of five monitoring sites on Dau Tieng Reservoir

Sampling site	North	East
DT1	11°20'32,8"	106°19'39,1"
DT2	11°25'20,2"	106°22'09,3"
DT3	11°27'48,4"	106°23'39,7"
DT4	11°23'40,8"	106°17'04,2"
DT5	11°26'47,8"	106°15'17,2"

To match the obtained cyanobacterial data, the main data used in this study is optical satellite images, produced by acquiring the energy of the visible light area (wavelength 0.4-0.76 μm) and infrared reflected from the object and the Earth's surface. The main source of energy is solar radiation. The duration of the study to select satellite images depends on the available data sources collected. Algal concentration measurements on the Dau Tieng Reservoir were observed in 2012 and 2013, so satellite images must also be collected around this time. Landsat satellite images have a wide range of environmental and resource monitoring applications. However, because optical image characteristics are susceptible to weather and environmental conditions, choosing images of good quality, not covered by clouds that lose the observation object is necessary. So, the dry season time is the best choice. The study period is the period of the active Landsat 7 satellite. Although the striped image data is defective due to signal loss, in the area of Dau Tieng Reservoir, there is no striped error, and only a few minor errors are insignificant. So the Landsat 7 satellite image source is used for research. The area of the scene with the range/line (path/row) is 125/052. Satellite image acquisition time on November 27, 2012, January 26, 2013, and February 27, 2013, were selected on the same day as the sampling time. The total ground sample data set is 15, including 5 samples at 5 sampling sites at 3-time monitoring points.

In addition to satellite image data and ground observation measurements, the study used supporting data, including (i) Topographic base map digitized according to VN-2000 coordinate system at 1:25,000 scale, collected from Map Publishing House, used to correct geometries for satellite images and present maps; (ii) GoogleEarth image data, this data source usually has a very high resolution (about 1 m depending on the area) used for reference, collating observation objects from Landsat images; this study used GoogleEarth image data at the corresponding years according to Landsat images.

3.2 Method

A remote sensing database is an electromagnetic wave reflected or radiated from objects. The sensors then pick up these electromagnetic waves on the carrier (Röder & Hill, 2007). Remote-sensing images with different colours and characteristics are created depending on the received electromagnetic wavelength. The remote sensing image provides information about objects corresponding to the radiant energy corresponding to each identified wavelength. Measure and analyze the spectral reflection energy recorded by remote sensing images, allowing to separate helpful information about each different type of ground cover due to the interaction between electromagnetic radiation and the object (Trung, 2015). The object of the study is the presence of cyanobacteria in the reservoir. Therefore, the determination of the spectral reflection of algae or, more specifically, the spectral reflection of Chlorophyll-a present in cyanobacteria underlies the analysis algorithm. Studies show that the Chlorophyll-a component tends to absorb high electromagnetic radiation at wavelengths in the BLUE band (~430 nm) and RED band (~686 nm) (Augusto-Silva et al., 2014; Richard et al., 2018), while very strong reflection at wavelengths in the GREEN band (~550 nm) due to chlorophyll component, and Near-Infrared band (~715 nm) due to reflection from plant cell walls (Augusto-Silva et al., 2014). Therefore, BLUE and RED bands are ones where the Chlorophyll-a component absorbs well with solar radiation, while GREEN and NIR bands are well-reflected bands. Therefore, developing qualitative algorithms and quantifying algae concentration in the Dau Tieng Reservoir was built based on these image bands.

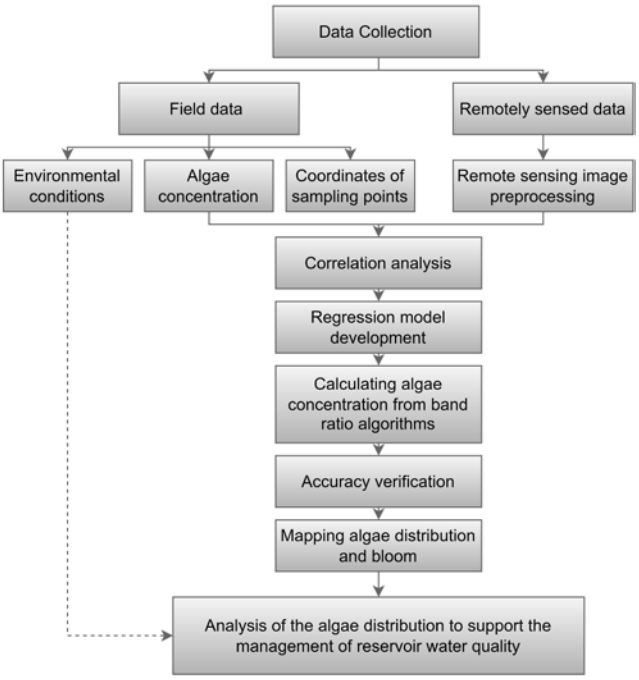


Figure 3. Methodological flow

Figure 3 presents the methodological diagram of this study. In there, we used two algorithm combinations to qualitatively evaluate the presence of algae in the Dau Tieng Reservoir, including the two bands algorithm (2BDA) and the three bands algorithm (3BDA). These algorithms are developed using the band ratio method. The band ratio method is based on the colour range of the image band that is strongly sensitive to the domestic components. Scaled images are calculated by dividing the values of each image pixel to highlight the image elements and eliminate noise, thereby highlighting the research object (Phi et al., 2014). The two bands algorithm was developed based on the ratio between a band that reflects well and a band that absorbs well the electromagnetic radiation from the research object algae. The GREEN and NIR bands give good reflectivity, while the BLUE and RED bands absorb radiation the best. However, the overlapping and uncorrelated absorptions between CDOM (Chromophoric Dissolved Organic Matter) and NAP (Non-Algal Particles) in the BLUE region of the spectrum make the ratio BLUE/ GREEN not provide an accurate estimate of Chlorophyll-a concentrations in waters where these components are not correlated with phytoplankton (Richard et al., 2018). Therefore, to retrieve Chlorophyll-a, the 2BDA algorithm generally focuses on the spectral characteristics of Chlorophyll-a in RED and NIR bands (Augusto-Silva et al., 2014; Richard et al., 2018; Willibroad & Sang-il, 2020). Besides the strong reflectance of Chlorophyll-a by the NIR band and the strong absorption by the RED band, the NIR band is the one in which water almost wholly absorbs the incident radiation. (Trung, 2015). It makes the water segregation of the 2BDA using the NIR band more effective. The mudflat areas or dunes in the reservoir are more clearly separated, limiting the misleading areas where algae have a high concentration. Besides the 2BDA of the NIR and RED bands, we will further test the effectiveness of the NIR and GREEN band ratio (also a strong reflection band and a strong absorption band). In addition, we also consider not using the NIR band but instead the ratio of the GREEN and BLUE bands, which are not considered to be descriptive of the phytoplankton presence in the water bodies (Richard et al., 2018). Below are the 2BDA used presented in Eq. (1), (2), and (3).

$$2BDA(1) = NIR/RED \quad (1)$$

$$2BDA(2) = GREEN/BLUE \quad (2)$$

$$2BDA(3) = NIR/BLUE \quad (3)$$

The basis of the 3BDA algorithm is similar to 2BDA based on the band ratio method. However, a third band instead of two bands was used to eliminate the influencing factors (Phi et al., 2014). As shown in the previous section, BLUE, GREEN, RED, and NIR bands are commonly used in remote sensing to determine algae concentration. Eq. (4), (5), and (6) presents the 3BDA algorithm using three of these four bands:

$$3BDA(1) = (GREEN+NIR)/RED \quad (4)$$

$$3BDA(2) = (BLUE-RED)/GREEN \quad (5)$$

$$3BDA(3) = (GREEN^{-1}+NIR^{-1})/RED \quad (6)$$

Eq. (4) was used in Bee's studies (2009) and Phi et al., (2014). In this equation, adding the GREEN band helps capture the amount of radiation reflected from the enhanced algae components, which can help better identify the presence of algae in the reservoir (Bee, 2009). The Eq. (5) was used in the studies of Richard et al., (2018) and Ho et al., (2017) which was recommended for low algae aquatic areas using short-wavelength imaging bands instead of NIR bands. It is similar to the Eq. (4) when using the ratio between strongly absorbed and strongly reflected radiation bands. However, subtracting the RED band in the equation helps remove non-algae elements (which may be alluvial or suspended sand particles if the area has sand mining activities), affecting the ratio of BLUE and GREEN bands (Richard et al., 2018). The Eq. (6) is empirically developed by our research. It was developed based on the Eq. (4) with the inverse of the GREEN and NIR band and has been tested with the calculation results that will be presented in the Results and Conclusion below.

The statistical method used is correlation and regression analysis. The correlation analysis is used to study the relationship between phenomena or between variables. The relationship between the two variables can be evaluated by considering the correlation coefficient between them calculated from the sample data set. The greater the absolute value of the correlation coefficient, the closer the linear relationship between the two variables. A positive correlation coefficient reflects the same direction relationship (covariate); conversely, a negative correlation coefficient indicates the inverse relationship (inverse variable) between two variables (Nickolas, 2021). The correlation method includes single linear and non-linear correlation (quadratic) to denote and analyze the relationship between ground measurements and spectral values extracted from satellite images at the monitoring point. Single correlation coefficients help to determine the degree of relationship between two variables.

Regression analysis is the process of estimating or forecasting a variable based on the given value of other variables. Technically in regression analysis, the variables do not have symmetric properties. The result of regression analysis is to find the type of regression model. The form of the regression model is an important issue that is decisive for the study's results. However, this problem does not have a rationale strong enough to confirm that the form of the regression model is this regression function rather than another regression function. The regression model is an empirical problem (Quang, 2008). Therefore, to increase the accuracy of regression analysis, we used both regression equation forms $y= a+bx$ and quadratic regression equation $y= ax^2+bx+c$ ($a \neq 0$).

The linear regression equation $y= a+bx$ is graphically represented as straight lines. On this graph, the lines are theoretical regression lines, which adjust and compensate for random differences to symbolize the linear correlation between the two variables considered. In the equation $y = a+bx$, y is a dependent variable; x is an independent variable; a and b are coefficients that must be determined. Coefficient a is the first derived level of the regression line, the free parameter independent of x. The coefficient b is the degree of slope regulation of the regression line, also known as the regression coefficient, which refers to the degree of influence of the independent variable x on the dependent variable y, namely that each time x increases to a value, y increases the average to a value b (Quang, 2008). The advantage of the linear regression equation is its simplicity; however, it is also a disadvantage to be too dependent on x.

The quadratic regression equation $y= ax^2+bx+c$ ($a\neq0$) is represented as a parabolic curve. In this equation, y is a dependent variable; x is an independent variable; a, b, and c are coefficients that must be determined. When x increases by 1, y increases by a fraction equal to b+2ax units; if $a >0$, then the effect of x on y increases. Conversely, if $a < 0$, the effect of x on y decreases. It creates the advantage of a quadratic regression equation over a linear regression equation when it is no longer too dependent on the variable x (Huy, 2010).

The error of evaluating the accuracy of quantitative results based on the regression equation is calculated from the average deviation (Bias) and root mean square error (RMSE) between the calculated values and the actual measurement value according to Eq. (7) and (8):

$$\text{Bias} = \frac{1}{n}\sum_{i=1}^{n}(\boldsymbol{X} - \boldsymbol{X}^*) \quad (7)$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(\boldsymbol{X}-\boldsymbol{X}^*)^2}{n}} \quad (8)$$

where n is the number of samples taken, X is the real value, and X* is the calculated value from the satellite images.

4. RESULT

4.1 Correlation analysis to determine the regression function

The total sample data set was 15 of 3 sampling times on November 27, 2012, January 26, 2013, and February 27, 2013, of which 10 samples were used to run regression and 5 samples to perform validation. Similarly, we extract 15 corresponding spectral values at 5 terrestrial sampling sites from 3-time points of satellite images according to the band ratios selected after correlation calculation. The dependent variable (y) is the concentration of algae (mg/l) that needs to be simulated to map the spatial distribution over the entire reservoir. The independent variables (x) are the band ratios calculated from the spectral values of the satellite image bands acquired on the equivalent date and used in the equations described above.

To assess the coherence of the relationship between the spectral value calculated from the algorithms and the measured algal biomass data, we used the Coefficient of determination, commonly referred to as the R^2 coefficient. R^2 values range from 0 to 1. The model's correlation level is closer as the R^2 value progresses to 1 (Trong & Ngoc, 2005).

The results of the correlation analysis according to the equation y= a+bx of the algorithm showed that the 2BDA(2), 3BDA(1), and 3BDA(2) presented a poor correlation between the concentration of algae at the monitoring points and the qualitative results ($R^2 < 0.1$) (Figure 4a). In the above three algorithms, the 3BDA(1) and 3BDA(2) were two algorithms that did not clearly express the distribution of algae concentration in the reservoir. The 2BDA(2) is an algorithm that can not evaluate the presence of phytoplankton in aquatic areas (Richard et al., 2018). The two algorithms, 2BDA(1) and 2BDA(3) gave correlation analysis results between the two algorithms were 0.2763 and 0.3185, respectively. It was not close enough to be used as a regression equation to quantify algal concentration. These are two 2BDA that use the NIR band in the formula. The 3BDA(3) algorithm gave the highest R^2 result of 0.6008 and showed the degree of the close correlation between qualitative results and the algae concentration in the Dau Tieng Reservoir.

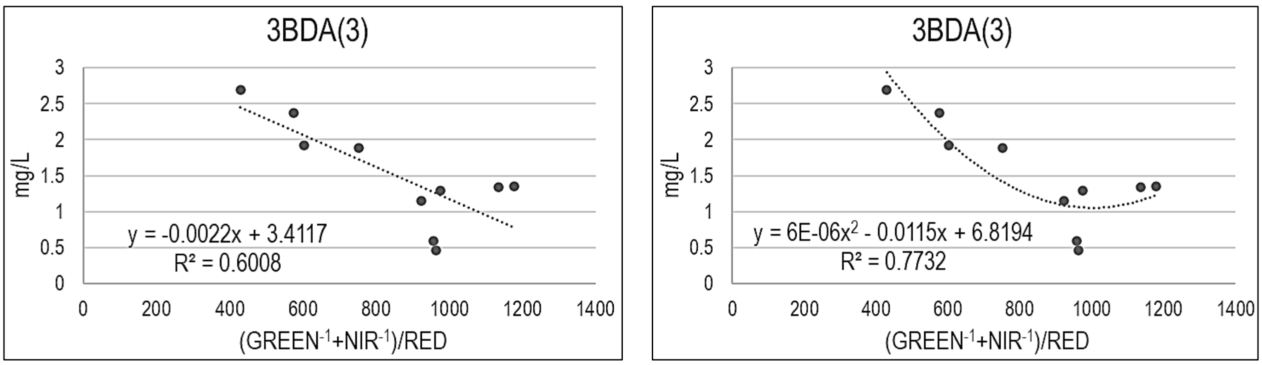
The results of the correlation analysis according to the quadratic equation $y= ax^2+bx +c$ show that the R^2 value of the algorithm increases compared to the linear equation y= a+bx (Figure 4b). The 3BDA(1) results in $R^2 < 0.1$, indicating that the algorithm is unsuitable for the research topic. The two algorithms that do not use the NIR band are 2BDA(2) and 3BDA(2), which give good correlation results, but R^2 values only reach 0.2524 and 0.2858. Therefore, these algorithms are also not suitable for this research. The R^2 values of the 2BDA(1) and 2BDA(3) also increased, especially the 2BDA(1) for R^2 value of 0.5303 exhibiting a high degree of correlation, as shown, which are also algorithms commonly used in studies on remote sensing assessment of algae concentration. However, the R^2 value is not high yet, while the 3BDA(3) gives an R^2 value of 0.7732, close to a very close correlation level. Therefore, the 3BDA(3) and its regression equations were used to quantify the algal concentration distribution in the Dau Tieng Reservoir. The regression equations are shown in Eq. (9) and (10):

$$y = -0{,}0022x + 3{,}411 \quad (9)$$

$$y = 6{,}10^{-6}x^2 - 0{,}0115x + 6{,}8194 \quad (10)$$

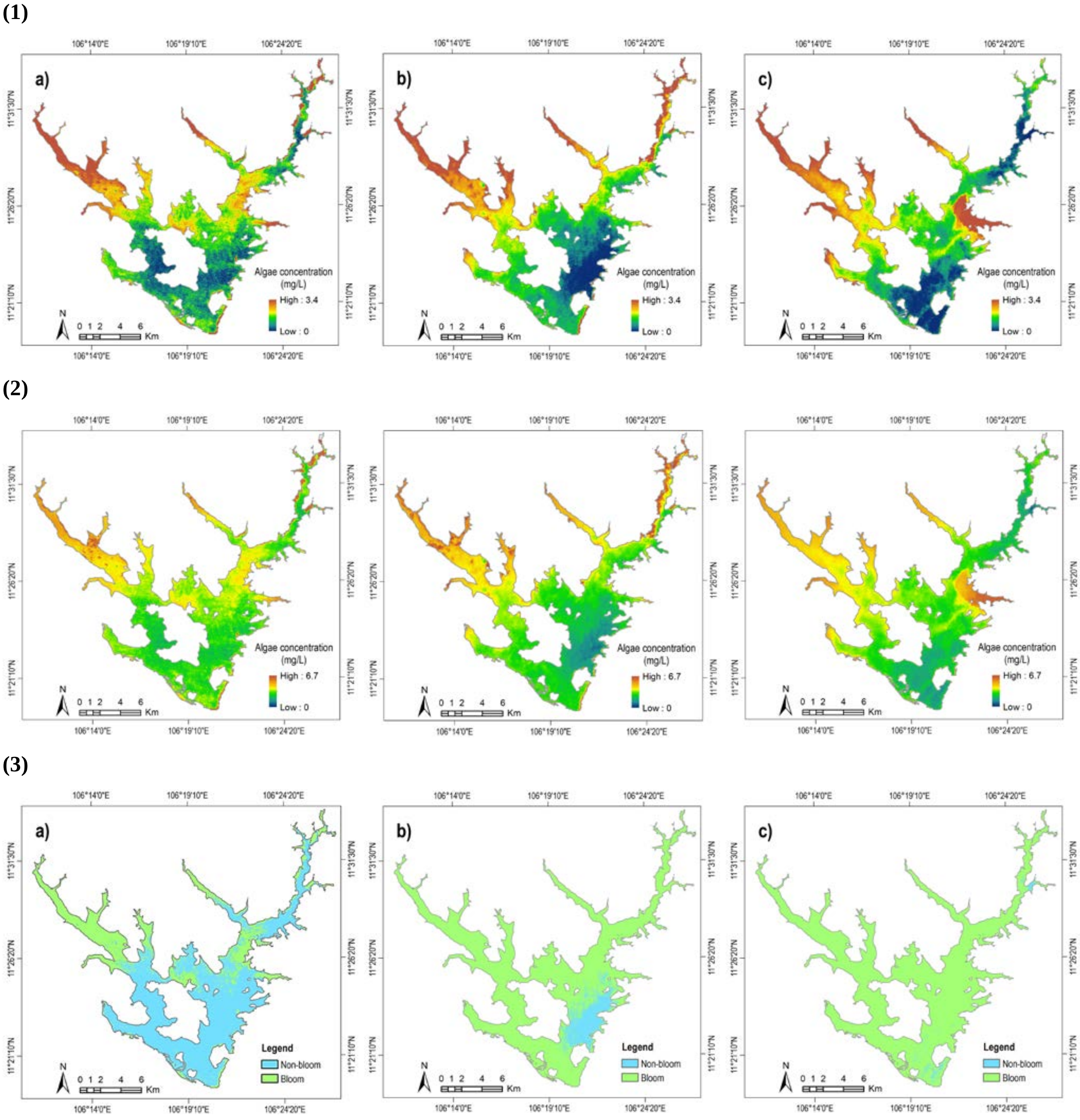
4.2 Mapping algae distribution

The 3BDA(3) calculation results according to the two regression equations are shown in Figure 5(1) and Figure 5(2). The quantitative calculation data were compared with the measured results to check and compare the accuracy of the two regression equations. Calculating the error according to the Bias and RMSE criteria shows that the Bias and RMSE deviations of the equation y= ax+b is relatively small and better than the regression equation $y= ax^2+bx+c$. Quantitative results from equation y = ax+b with Bias = 0.59 and RMSE = 1.39 are acceptable, while results from equation $y= ax^2+bx+c$ with Bias = 1.57 and RMSE = 3.55 are worse than linear regression equations. Therefore, although the R^2 value of the quadratic regression function is higher than the linear regression function, the quantitative calculation results of the linear regression function give more relevant calculation results than the quadratic regression function. From the quantitative calculation results, the study mapped and evaluated cyanobacterial biomass in the Dau Tieng Reservoir through the flowering value threshold according to the cyanobacterial concentration. The bloom threshold



(a) (b)

Figure 4. Results of correlation analysis on the data set of ground samples and satellite images at 3 observation times in 2012-2013 according to the equation (a) y= a+bx; (b) $y= ax^2+bx +c$



(a) November 27, 2012 (b) January 26, 2013 (c) February 27, 2013

Figure 5. (1) Quantitative calculation results according to regression equation y= a+bx; (2) Quantitative calculation results according to regression equation y= ax^2+bx+c; (3) Distribution of algae blooming on Dau Tieng Reservoir

was based on the cyanobacterial concentration as determined by the cell density and the mass of 1 cyanobacterial cell. Specifically, the harmful bloom threshold is defined as when the density of algae cells exceeds 100,000 cells/ml of water, and the mass of 1 alga cell is $1.2*10^{-8}$ mg/cell for cyanobacteria (Wenna Hu, 2014). From there, the threshold concentration of blooming cyanobacteria was determined at 1.2 mg/L.

The results of bloom threshold analysis on the Dau Tieng Reservoir (Figure 5(3)) show that in November 2012, the phenomenon of algae blooming appeared only in some areas, such as the Northwest and the East of the reservoir. However, by January 2013, algae blooming spread to a large area, except in the reservoir's southeast. In February 2013, most of the algae blossomed in the reservoir area, except a tiny part of the south, near the Dau Tieng reservoir discharge dam. It is consistent with some algae bloom incidents in Vietnam around January to March (Quang & Vien, 2018). The Northwest and the East areas of the reservoir were in a state of blooming algae over the monitoring period. For all three months, the concentration of algae in the Northwest region was always higher than 2.2 mg/L and ranged from 2.2 to 3.4 mg/L. For the eastern area of Dau Tieng Reservoir, in January 2013, the concentration of algae ranged from 1.6 to 3.1 mg/L. However, in November 2012 and February 2013, the concentration of algae was always higher than 2.5 mg/L, the highest at 3.4 mg/L (Figure 5(1)).

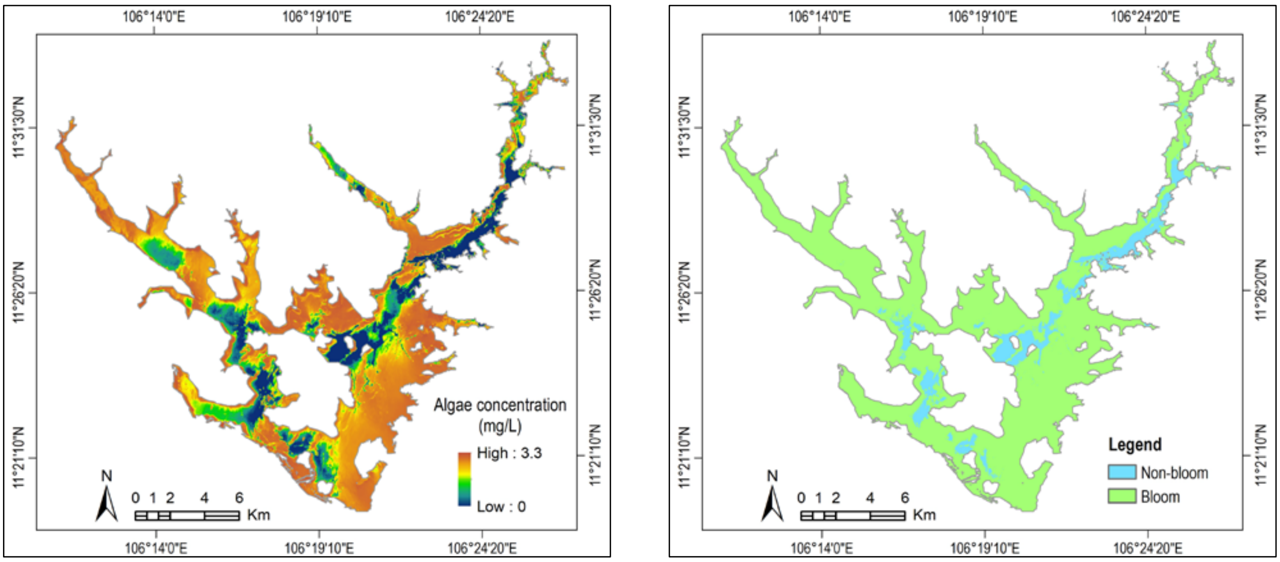
We continued to survey for 2021 by field trip to survey algae blooms on the Dau Tieng Reservoir and marked areas with signs of algae blooms. Besides, we also conducted a survey and recorded the human activities that can potentially affect algae growth, such as sand mining, fish cage farming, agricultural farming, etc., to understand the algae-bloom reason. Input data was Sentinel-2 image acquired on March 26, 2021, suitable for the field survey time from March 25, 2021, to March 29, 2021. The reason for using Sentinel-2 images is that the field survey period is between the iteration period of Landsat 7 and Landsat 8 satellites. Therefore, no Landsat satellite acquisition images are close to field survey time. However, the wavelengths of the Sentinel-2 satellite images in the visible light range are similar to those of the Landsat satellite. It helps limit the difference when using images received from the two types of satellites. Besides, with a spatial resolution of up to 10m, the Sentinel-2 satellite provides more detailed images than Landsat 7 and 8 satellites (30m resolution).

The algae quantitative results according to algorithm 3BDA(3) and regression function $y = -0.0022x + 3.4117$ for March 26, 2021, are shown in Figure 6a. The highest concentration of algae was determined at 3.3 mg/L. Algae concentration distribution in 2021 differed from that in the dry season 2012-2013, specifically in the reservoir's southeast area; algae concentration was not high. In November 2012 and January 2013, the concentration of algae in this area did not reach the blooming threshold of 1.2 mg/L. However, the calculation of algae concentration on March 26, 2021, showed that the concentration of algae in the southeast area of the reservoir fluctuated in the range from 2.5 to 3.2 mg/L. In the northwestern and eastern areas of the reservoir, the algal concentrations were quite similar to the 2012-2013 dry season results, ranging from 2.2 to 3.3 mg/L. In a small area in the northwest area of the reservoir, algae concentrations ranged from 1.1 to 1.5 mg/L. It was the most extensive sand mining area in Dau Tieng Reservoir; the sand mining has stirred up the water environment and, at the same time, reduced the photosynthetic ability of algae, making the algae grow slower than in other areas. Performing algae bloom threshold showed that algal blooms occurred in most reservoir areas (Figure 6b). Some areas that have not yet occurred algal bloom are located in a small part of the west and northeast of the reservoir.

4.3 Analyze the causes of algal blooms and propose management solutions

Through the above calculation results in the dry season period 2012-2013 and March 2021, it has been shown that the algal bloom on the Dau Tieng reservoir has not decreased significantly. Although the authorities of Tay Ninh and Binh Duong provinces have issued decisions to manage reservoir water quality, such as banning fish cage farming or regulating sand mining activities, etc., algal blooms still appear. In addition, the natural features of Dau Tieng Reservoir are essential factors in promoting algal blooms. Algae species and blue algae generally prefer aquatic environments with warm temperatures, low disturbances, and high nutrient content. Dau Tieng Reservoir has an average annual temperature of 27.4°C, abundant year-round light, and an average of 6 hours of sunshine per day (Tam, 2007) which are suitable conditions for algae growth. Besides, with an annual flow modulus of 20-25 l/s-km^2, the water flow in the Dau Tieng Reservoir is lower than in other lakes around (Tuan, 2011), which creates a less disturbed water environment favourable for the growth of algae. Finally, algae growth in the Dau Tieng Reservoir almost depends on the remaining conditions, which is the nutrient content in the reservoir, especially the nitrogen and phosphorus content. The nutrient sources of the reservoir come from fish farming activities, agricultural fertilizers, cattle farming, and two rivers (Cham and Tha La) running and water from other places pouring into the Dau Tieng Reservoir. Figure 7 shows some environmental conditions leading to algal blooms in some areas of the Dau Tieng Reservoir during the field trip in March 2021.

The environmental conditions discovered during the survey from March 25, 2021, to March 29, 2021, showed that cage-raft farming still occurred in some reservoir areas. However, the People's Committees of Tay Ninh and Binh Duong provinces have issued decisions banning cage-raft fish farming (a floating structure consisting of fish rafts, fish cages, and raft houses used for aquaculture on seas, rivers, lakes, and lagoons). Almost all sites where cage-raft fish cultures were recorded showed relatively high concentrations of algae, ranging from 2.1 to 3.3 mg/L. It was appropriate because the leftovers from the fish culture are an essential source of nutrients for the algae.



(a) (b)

Figure 6. (a) Spatial distribution of algal concentration and (b) bloom in the Dau Tieng Reservoir on March 26 2021

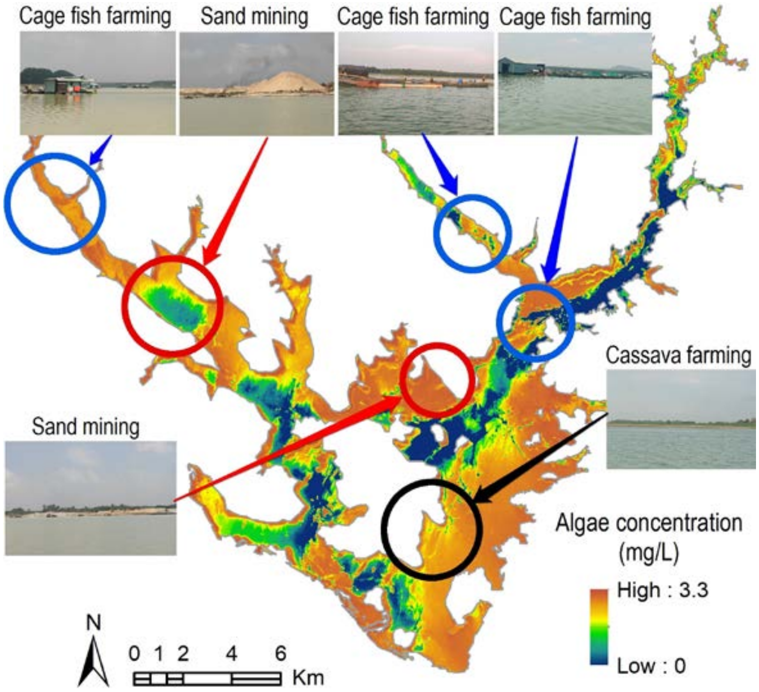


Figure 7. Some anthropogenic activities on the Dau Tieng Reservoir from the field survey

(a) (b) (c)

Figure 8. (a) The Tha La Lake and (b) the water hyacinth overflowing its dam, (c) and the sand overexploitation in the Dau Tieng Reservoir

Besides, the waste of fish, fish carcasses, and waste of livestock households also contributed significantly to the phenomenon of eutrophication. In addition to cage-raft fish farming, crops, specifically cassava, have been recorded in alluvial mudflats in the middle of the reservoir. In the rainy season, rainwater overflowed on the surface, carrying fertilizers used in the cultivation process into the reservoir.

Another cause of algal blooms in Dau Tieng Reservoir, especially in the northwest reservoir region, was the water reception from Tha La Lake (Figure 8a). Tha La Irrigation Lake has an area of more than 300 hectares, located in Tan Chau district, in the upstream area of Dau Tieng Reservoir. The excess water of Tha La Lake has flowed into Dau Tieng Reservoir through the artificial spillway (Figure 8b). Tha La Lake is the place to receive domestic and production wastewater from factories. As a result, the lake water quality has a high nutrient content, as evidenced by hyacinth plants and weeds that thrive in the lake (Quoc, 2021). During the rainy season or at high tide, water from this lake overflows through the rubber dam (Tha La Lake spillway is installed with a rubber bag) adjacent to the Dau Tieng Reservoir, bringing much water and water hyacinth into Dau Tieng Reservoir. After leaving Tha La Lake, the hyacinth stagnates and proliferates, blocking the flow into Dau Tieng Reservoir. Besides, when water hyacinth die and decompose, it forms a source of nutrients in the water. It has created ideal conditions for algae, mainly blue-green algae, to grow. In the rainy season, the large water flow swept this amount of algae into Dau Tieng Reservoir, causing the concentration of algae in the northwest of the reservoir to increase significantly.

For sand mining activities on the Dau Tieng Reservoir, the results of the calculation of algae concentration have shown that in the area where sand mining activities took place, the concentration of algae was lower than in neighbouring areas. It is due to a disturbed aquatic environment and suspended sand particles that reduce the ability of algae to photosynthesize. However, sand mining has vigorously stirred the bottom layer, causing the phosphorus deposited in the bottom layer to rise. As a result, Total Phosphorus (TP) levels increase. When TP concentrations spread to stable water bodies, it creates favourable conditions for algae to thrive (Dao, 2013). Therefore, sand mining activities can reduce the concentration of algae in the mining area but increase the growth conditions for algae in nearby stable waters. In some areas of the reservoir, sand mining activities took place massively. After absorbing all the yellow sand, they continued to suck deep into the red sediment at the bottom of the reservoir (Figure 8c). It shows that the reserve of sand on the reservoir bottom was seriously decreasing, causing the risk of shore erosion.

The proposal for solutions to manage the water quality of Dau Tieng Reservoir in general and the problem of algal blooms, in particular, must be based on ongoing environmental conditions and the legal bases of the units responsible for managing Dau Tieng Reservoir. Special environmental conditions in the Dau Tieng Reservoir affect the reservoir's water quality, including sand mining, fish farming, agricultural cultivation in alluvial areas, and water pollution surrounding the reservoir.

As for sand mining, this activity is not prohibited at Dau Tieng Reservoir according to Decision No. 3172/QD-UBND of Tay Ninh province. However, the People's Committees of Tay Ninh and Binh Duong provinces only licensed a few units to operate. But in fact, many sand mining vessels are operating on the reservoir. The legal status of these sand mining vessels is unknown. However, the solution proposed here is that the authorities conduct regular inspections and supervise sand mining activities. The authorities should proceed to sanction the illegal sand mining vessels and check whether the licensed units' sand mining activities operate at the registered capacity.

Similar to sand mining, cage-raft fish farming has been banned according to Official Letter No. 344/UBND dated 2/11/2005 of the Chairman of Tay Ninh Provincial People's Committee; and Decision 06/2017/QD-UBND of Binh Duong province; However, cage-raft fish farming takes place stealthily and sporadically in some reservoir areas. Therefore, supervisory authorities must handle this activity.

For agricultural activities in alluvial plains in the reservoir area, although not directly polluting and affecting the reservoir water quality, local authorities can encourage people to limit the use of fertilizers, especially chemical fertilizers, in the rainy season to limit the overflow of rainwater and wash away fertilizers into the reservoir. In addition, local authorities must also inspect and supervise end-of-season harvesting activities and prohibit and treat the disposal of agricultural by-products into the reservoir.

Finally, managing water sources in the reservoir is the most challenging problem, requiring the coordination and management of many localities. Therefore, the first thing is that localities need to skilfully manage the discharge activities of factories and industrial parks to limit pollution of water sources, thereby limiting water pollution in the Dau Tieng reservoir. Cleaning up water hyacinths and weeds is also essential for clearing the flow and limiting algae growth.

5. CONCLUSIONS

This study analyzed satellite images using two-band 2BDA and three-band 3BDA algorithms in November 2012, January 2013, and February 2013 to find a suitable algorithm for calculating algal concentrations in the reservoir. The results of the correlation analysis between the qualitative calculation results and the algae concentration monitoring data showed that the 3BDA(3) algorithm showed the best correlation with the value $R^2 = 0.6008$.

Calculation results have shown that algae bloom took place in the northwest and east areas of the reservoir in November 2012 and gradually spread to all areas of the reservoir in January 2013 and February 2013. Further research for March 2021 showed that algal blooms were still taking place in most areas of Dau Tieng Reservoir. The reason was due to the nutrient content in the reservoir, especially the Nitrogen and Phosphorus levels from fish farming activities, agricultural fertilizers, and wastewater from other places pouring into Dau Tieng Reservoir. In addition, sand mining activities can reduce the concentration of algae in the mining area but increase the growth conditions for algae in nearby stable waters.

This study has demonstrated the ability of remote sensing technology to monitor algae in the reservoir. In reality, it is not easy to measure to understand the distribution of algae over a large lake with the level of detail from satellite images. The results have mapped the distribution of algal concentrations in space and pointed out the causes of algal blooms to support reservoir water quality management, providing an important water source for downstream areas.

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