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USING MULTISPECTRAL SATELLITE IMAGES TO ESTIMATE ALTERATION IN THE WATER SURFACE AREA OF LAKE DANKIA DURING THE 2020–2021 DRY SEASON, LAM DONG PROVINCE, VIETNAM

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Abstract

Vietnam in recent years, especially in the Central Highlands and the South Central region, is experiencing severe droughts due to global climate change, depletion of the surface water resources and intensive agricultural production. The study used four Sentinel 2 MSI satellite images received during the 2020–2021 dry seasons to evaluate alteration in the water surface area of Lake Dankia in the Lam Dong Province of the Vietnam Central Highlands. Optical green channel (channel 3) and shortwave infrared channel (channel 11) of the Sentinel 2 images were used to calculate the modified normalized difference water index MNDWI and to decipher the land–water boundary by the thresholding method. The obtained results demonstrated that the Lake Dankia area at the dry season end (March 18. 2021) decreased by 86.46 hectares compared to November 18. 2020 (dry season start), which was 31.7 % of the original lake area. This study shows that the Sentinel 2 MSI satellite images could be effectively used to monitor alterations in the surface water area and provide valuable input information for models to assess the drought impact on water resources in the areas

Keywords

Drought, remote sensing, MNDWI index, Sentinel 2 MSI image, Vietnam Central Highlands

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Introduction. Drought is one of the most costly natural disasters in the world and causes great damage in the socio-economic and environment sectors. In Vietnam, drought occurs in most of the country with varying degrees and duration, seriously affecting water resources and in agricultural production [1, 2]. Particularly for the Central Highlands region of Vietnam, drought is the natural disaster that has the most negative impact on life and production. In the dry season (from November to April next year), most of the irrigation reservoirs in Lam Dong province are in a state of water shortage, greatly affecting thousands of hectares of rice and industrial crops.

Surface water is one of the irreplaceable strategic resources for human survival and social development [3]. Reliable information about the spatial distribution of surface water is critically important in various fields, such as natural resources management, environmental monitoring [4, 5]. Remote sensing technology with advantages compared to traditional methods such as wide area coverage and short revisit interval has been used effectively in assessing the impacts of droughts on water resources [6–8]. Surface water can be clearly distinguished from other land cover objects due to the difference in spectral reflectance characteristics. In the near-infrared and short-wave infrared bands, water absorbs most of the electromagnetic radiation energy, so these spectral bands are often used to classify surface water. Many methods of surface water extraction from optical satellite images have been proposed, such as thresholding method [9, 10], band rationing method [11, 12] and spectral indices method [13, 14].

Water extraction by thresholding is usually performed on single band; however this method is not very accurate due to the confusion between water pixels and other land cover types. Classification techniques are more accurate than thresholding methods, although the accuracy of surface water extraction also depends on the traning data and the ability of the interpreter. Water indices calculated from multispectral satellite images have been effectively used in water body extraction compared with thresolding and classification methods. Until now, many water indices have been proposed for water extraction, such as Normalized Difference Water Index (NDWI) [15–18], Modified Normalized Difference Water Index (MNDWI) [19], Water Ratio Index (WRI) [20], Automatic Water Extraction Index (AWEI) [21]. These water indices were developed for the extraction of water features from Landsat imagery with 30 m spatial resolution. Due to the low spatial resolution of Landsat images, the use of water indices for small areas is limited. These limitations can be overcome when using Sentinel 2 MSI satellite images with higher spatial resolution, up to 10 m in visble and NIR band, 20 m in SWIR bands. Figure 1 presents the results of comparing the characteristics of Landsat 8 and Sentinel 2 MSI satellite image bands, in which the rectangles represent the waveband and bandwidth of each spectral band. Thus, it is possible to use the Sentinel 2 MSI bands such as green band (band 2), NIR band (band 8) and SWIR1 band (band 11) instead of the corresponding bands of the Landsat 8 data in calculating the water indices (NDWI, MNDWI, ...), which enhances the spatial resolution of these indices.

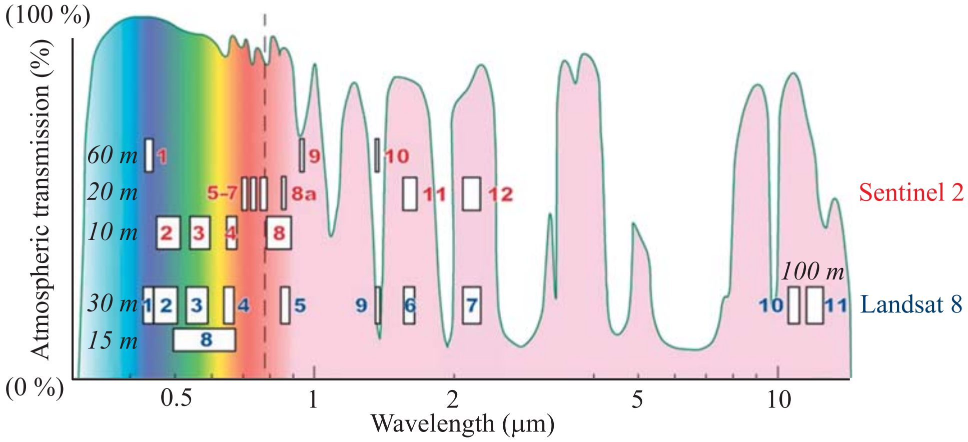

Fig. 1. Comparison of characteristics of Sentinel 2 MSI and Landsat 8 imageries [22]. The Earth's atmosphere transparency curve for electromagnetic radiation shows the approximate location of the spectral bands. See Table 1 for more information on Sentinel 2 MSI bands

Table 1

Sentinel 2MSI 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

The major concern in this study is to assess the surface area change of Lake Dankia (Lam Dong province, Central Highlands region of Vietnam) during 2020–2021 dry season based on Sentinel 2 multi-temporal data. The MNDWI index is used to water extract using the thresholding method. Image processing was performed using ERDAS Imagine 2014 software and shoreline change map was produced using ArcGIS 10 software.

In this study, a technological scheme for analyzing and interpreting Sentinel 2 MSI data was developed to assess the change in the water surface area. This is one of the first studies using Sentinel 2 MSI satellite images to calculate water indices and thereby assess the change in surface water area due to the effects of drought in the Central Highlands, Vietnam. The use of Sentinel 2 MSI high spatial resolution data in extracting surface water information also helps to improve the efficiency of remote sensing data application in monitoring the changes in small water reservoirs such as Lake Dankia (Lam Dong Province).

Study areas and materials. *Study areas.* Lake Dankia is a cluster of lakes in Dankia village, Lac Duong district, Lam Dong province (Fig. 2). It is located about 20 km north of Dalat city — the center of Lam Dong province. Lake Dankia consists of two lakes, Lake Dankia above and Lake Ankroet below with an average area of about 245 hectares in the dry season. The lake was built in 1942 with a capacity of 21 million m^3 to serve the Ankroet hydroelectric power plant. Today, the lake is the main source of domestic water supply for Da Lat city and Lac Duong district, with a daily capacity of about 74 000 m^3.

The climate in the study area is divided into two distinct seasons: the rainy season from May to October and the dry season from November to April. In recent years, Lam Dong province often faces severe drought due to the effects of climate change and the reduction of forest area.

Materials. In this study, 04 Sentinel 2 MSI scenes taken on November 18. 2020, February 16. 2021, February 26. 2021 and March 18. 2021 were used to compute the MNDWI index. The Sentinel 2 data products in level-2A were downloaded from the Copernicus Data and Information Access Service (DIAS) cloud environments. This data is availabe in the website [23]. The Sentinel 2 image data is pre-processed to remove radiometric and geometric errors, and then cut along the boundaries of the study area. Figure 3 shows 04 Sentinel 2 images of Lake Dankia in 2020–2021 dry season with color combination RGB = SWIR : NIR : RED.

Methodology. The NDWI index was proposed by McFeeter on the basis of the high reflectivity of water at green band (0.52–0.60 μm) and strong absorption at near infrared band (0.76–0.90 μm). The NDWI index is calculated by the following formula McFeeters [15]:

$$\mathrm{NDWI} = \frac{\rho_{\mathrm{GREEN}} - \rho_{\mathrm{NIR}}}{\rho_{\mathrm{GREEN}} + \rho_{\mathrm{NIR}}}, \tag{1}$$

where ρ_{GREEN} and ρ_{NIR} are reflectance values of green and near infrared bands.

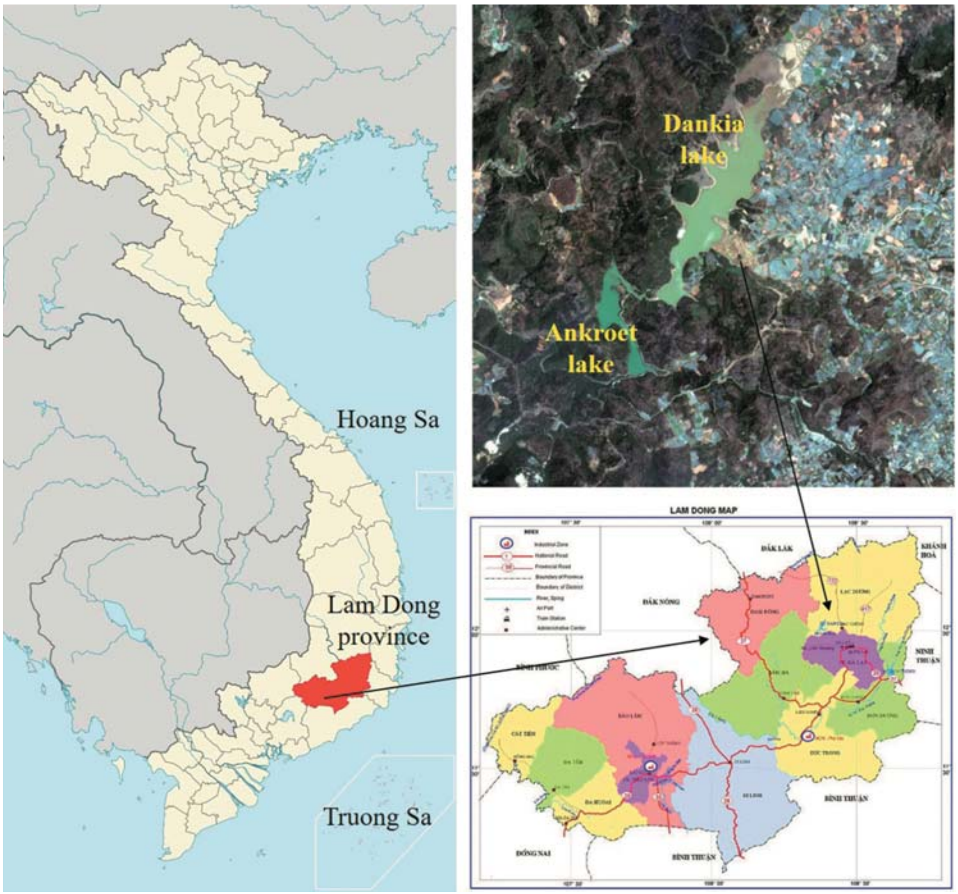

Fig. 2. The study area: Lake Dankia in Lam Dong province, Central Highlands of Vietnam

Since surface water extracted using the NDWI index include false positives from built-up land, a modified NDWI (MNDWI) was developed by Xu [19], in which the shortware infrared band (SWIR1; 1.55–1.75 μm) was replaced with the near infrared band. Many studies have shown that SWIR1 band has the high degree of absorption by water and strong reflectance by vegetation and soil [11, 24]. The MNDWI index is calculated by the formula:

$$\mathrm{MNDWI} = \frac{\rho_{\mathrm{GREEN}} - \rho_{\mathrm{SWIR1}}}{\rho_{\mathrm{GREEN}} + \rho_{\mathrm{SWIR1}}}. \tag{2}$$

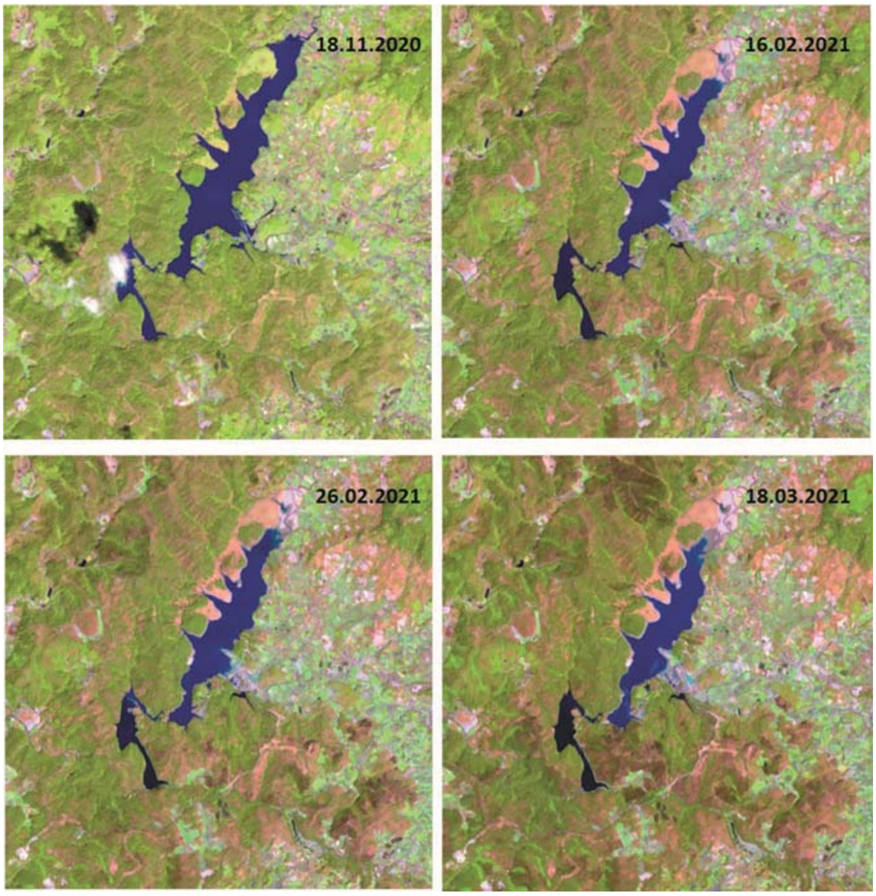

Fig. 3. Sentinel 2 multispectral images in Lake Dankia in 2020–2021 dry season, RGB = SWIR : NIR : RED

Flowchart for the methodology used in this study to detect the surface water change using Sentinel 2 MSI data is shown in Figure 4.

Results and discussion. Sentinel 2 MSI data is collected at the L2A processing level (Bottom of atmosphere reflectance value), so in this study, only geometric correction was carried out to convert to the local coordinate system VN-2000. Green and shortwave infrared bands of Sentinel 2 MSI imageries in 2020–2021 dry season were used to compute the MNDWI index according to the equation (2). The MNDWI indices calculated from Sentinel 2 MSI data in this study are shown in Figure 5.

The surface water has a very bright white colour on the MNDWI image due to the spectral reflectance value of the water in the green band is much higher than that of the SWIR1 band. In contrast, the reflectance values of vegetation and soil in the green band are lower than SWIR1 band, and these objects are shown in dark colour on the MNDWI image (see Fig. 5).

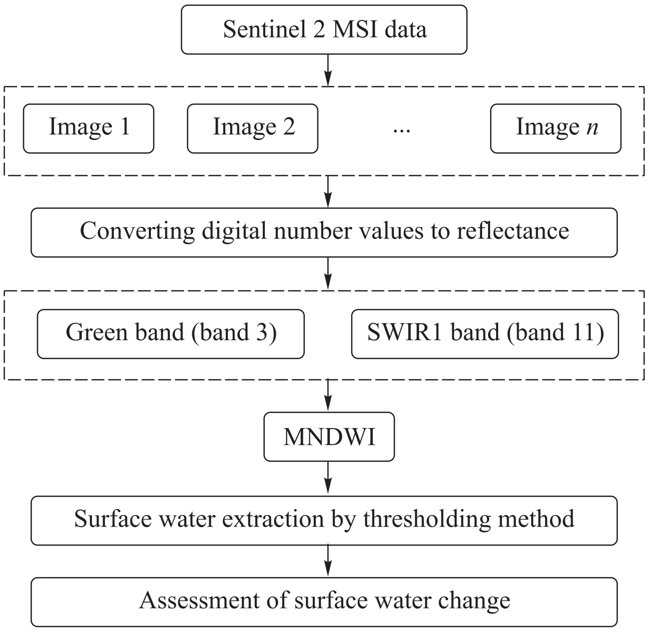

Fig. 4. Flowchart of the methodology for surface water change detection

Fig. 5. MNDWI indices, calculated from Sentinel 2 MSI data in 2020–2021 dry season

The Otsu's thresholding method has been selected to extract surface water from MNDWI image. This algorithm assumes that the MNDWI image contains two classes of pixels, the histogram is bimodal histogram, and calculates the optimum threshold value such that the pixel types (within-class variance) can be separated or equivalent the between-class maximum variance [25]. The results of surface water extraction in Lake Dankia area from MNDWI images by Otsu thresholding method are presented in Figure 6 and Table 2.

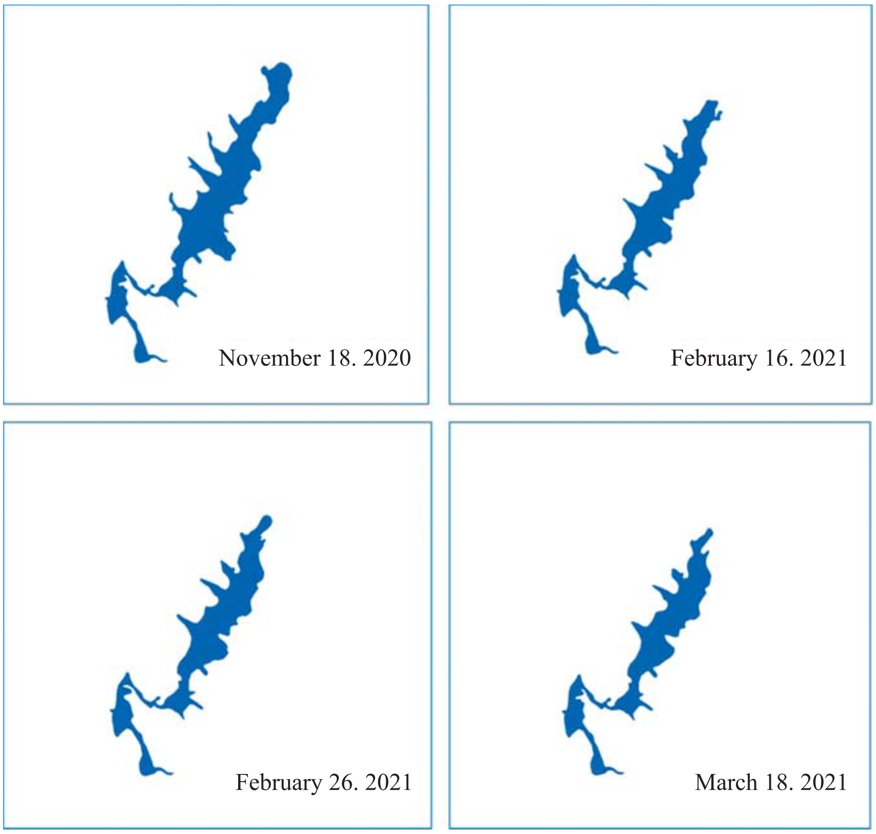

Fig. 6. The results of surface water classification using Otsu's thresholding method

Table 2

The surface water area in Lake Dankia, 2020–2021 dry season

No.	Time of data acquisition	The surface water area of Lake Dankia (ha)
1	November 18. 2020	272.91
2	February 16. 2021	204.98
3	February 26. 2021	197.80
4	March 18. 2021	186.44

The κ coefficient was used to assess the classification accuracy of surface water from MNDWI indices. In the study, the authors extracted random water and non-water pixels on the original image to evaluate the accuracy of the OTSU algorithm in the extraction of surface water. The κ coefficient is determined according to the following formula:

$$\kappa = A / B, \tag{3}$$

where A is number of pixels that classify correctly minus number of pixels that classify incorrectly; B is total number of pixels classified. When $\kappa = 1$, the classification accuracy is absolute.

In this study, 150 random points were taken to assess accuracy of water-non water classification. The obtained results show that the number of pixels correctly classified into the surface water object for Sentinel 2 MSI images on November 18. 2020, February 16. 2021, February 26. 2021 and March 20. 2021, respectively. are 141, 144, 143 and 142; the number of incorrectly classified pixels is 9, 6, 7, 8, respectively. As can be seen, the surface water classified from the MNDWI index has high accuracy, the κ coefficient value for Sentinel 2 images taken on November 18. 2020, February 16. 2021, and February 26. 2021 and March 18. 2021 are 0.880, 0.920, 0.907 and 0.893 respectively.

Analysis of the obtained results shows that the surface water area of Lake Dankia has a continuous decline in the dry season 2020–2021, from 272.91 hectares at the beginning of the dry season (November 18. 2020) to 186.44 hectares at the end of the dry season (March 18. 2021), equivalent to 31.7 % of the lake area. The dried-up lake region is concentrated mainly in the north of Lake Dankia — the upstream area where the Dadong river and Dalien Deur stream into the lake. Surface water in the downstream area of Lake Dankia, where the water level is relatively deep, does not change significantly. The spatial distribution change in surface water area of Lake Dankia in the dry 2020–2021 season is presented in Figure 7. It can be seen that with a large decrease in surface water area, a large volume of water in Lake Dankia is also reduced due to the effects of drought in this time period.

Conclusion. In this study, Sentinel 2 MSI remote sensing image data collected during the dry season 2020–2021 was used to assess the change in surface water of Lake Dankia (Lam Dong province, Central Highlands region of Vietnam) due to the effects of drought. The obtained results show that the surface water area of Lake Dankia decreased continuously from November 2020 (early dry season) to March 2021 (end of dry season). The water surface area of Lake Dankia on March 18. 2021 has decreased by 86.46 hectares compared to November 18. 2020, equivalent to 31.7 % of the lake area.

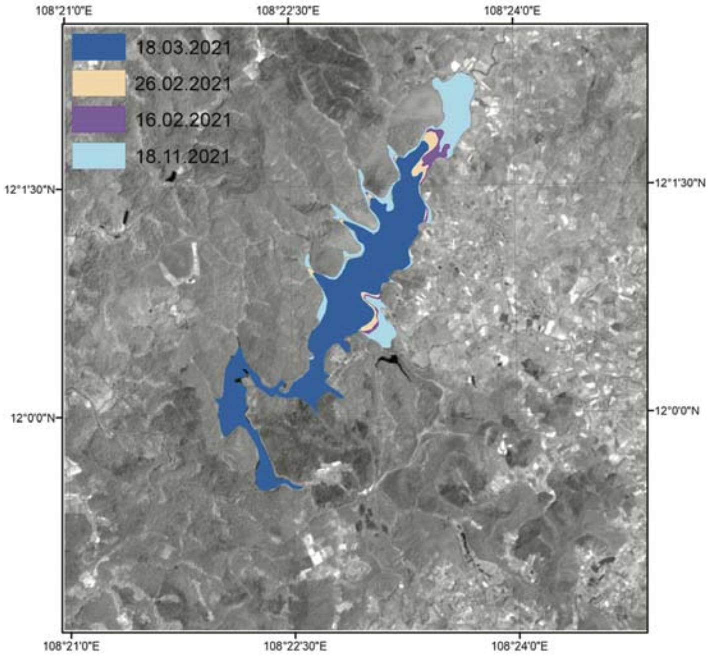

Fig. 7. The spatial distribution change in surface water of Lake Dankia in the 2020–2021 dry season

Sentinel 2 MSI data have the highest spatial resolution up to 10 m, 5-day temporal resolution can be effectively used in studying the impact of drought on surface water resources. The method and results obtained in the study can be used for climate models, as well as for the management and rational use of surface water resources.

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