ADVANCES IN GEODESY AND GEOINFORMATION
(formerly GEODESY AND CARTOGRAPHY)
Vol. 73, no. 2, article no. e56, 2024

https://doi.org/10.24425/agg.2024.150685

Original paper

Reservoir surface water area variations change research using Sentinel 2 MSI data. A case study in Dak Lak province, Central Highlands (Vietnam)

Le Hung Trinh[1*], Tran Xuan Bien[2], Khanh Hoai Dao[1]

[1]Le Quy Don Technical University, Hanoi, Vietnam
e-mail: trinhlehung@lqdtu.edu.vn; ORCID: http://orcid.org/0000-0002-2403-063X
e-mail: geogroup2008@gmail.com; ORCID: http://orcid.org/0000-0002-0529-3143

[2]Hanoi University of Natural Resources and Environment, Hanoi, Vietnam
e-mail: txbien.ph@hunre.edu.vn; ORCID: http://orcid.org/0009-0005-1113-1545

*Corresponding author: Le Hung Trinh, e-mail: trinhlehung@lqdtu.edu.vn

Received: 2023-12-16 / Accepted: 2024-08-03

Abstract: Agriculture is one of the most important economic sectors in Vietnam, however, in recent times, agricultural production has been negatively affected by drought, reducing crop productivity and quality. Due to the effects of climate change, drought occurs in most regions of the country with varying degrees and duration, seriously affecting water resources and agricultural production. Particularly for the Central Highlands region, drought is a natural disaster with the most negative impacts on life and production. This paper presents the results of monitoring the changes in water surface area of some reservoirs in Dak Lak province in the dry season in early 2020 from Sentinel 2 data. The MNDWI index calculated from green and NIR band of Sentinel 2 images is used to extract surface water, and thereby evaluating the change in surface water area of the reservoirs. The obtained results show a very strong decrease in water surface area of reservoirs in Dak Lak due to the influence of drought. The water surface area of Ea Sup Thuong Lake decreased about 6 times at the end of the dry season (May 2020) compared to the period of January 2020. The water surface area of Ea Uy Lake decreased about 4 times, while with the Krong Buk Ha Lake, the decrease in water surface area was lower, reaching about 28% compared to the beginning of the dry season. The results obtained in the study provide timely information to help managers effectively respond to the effects of drought on water resources.

Keywords: drought, remote sensing, Dak Lak province, surface water area, Sentinel 2 MSI

1. Introduction

Drought is one of the natural disasters causing great damage to the economy, society and environment (Thenkabail et al., 2004). Drought affects the environment, destroying plants and animals, reducing air and water quality, and increasing the risk of forest fires. Drought is also the leading cause of land degradation, leading to reduced crop productivity and quality, and social instability due to water resource conflicts. Global climate change leads to increasingly complicated droughts in many different regions of the world, including Vietnam – one of the most affected countries by climate change (Schmidt-Thome et al., 2014; Ishikawa-Ishiwata and Furuya, 2022). Drought has a major impact on surface water area changes in river and lake areas during the dry season. Under the impact of drought, water sources from rain are reduced or absent, leading to a significant decrease in water levels in rivers and lakes. When the surface water area decreases, negative impacts on the environment and human life can occur. At the same time, river and lake ecosystems may be affected, causing the degradation of biodiversity and reducing the quantity and quality of biological resources. In addition, reducing the amount of water in rivers and lakes also affects the use of water for irrigation, providing water for farms, industry, and human activities.

Droughts occur frequently in all regions of Vietnam, the most serious of which are the South Central Coast, Central Highlands and Southern regions (Vu et al., 2014). In the Central Highlands region, drought is the natural disaster that has the most negative impact on life and agricultural production, and is the leading cause of increased risk of forest fires and land degradation (Le et al., 2021). The Central Highlands is a region in Central Vietnam with plateau terrain, including 5 provinces with a natural area of 5454800 ha, accounting for 1/6 of the country's area. In the dry season (from November to April next year), most irrigation reservoirs in the Central Highlands are in a state of water shortage, greatly affecting thousands of hectares of rice and industrial crops. Monitoring and evaluating changes in the water surface area of reservoirs under the impact of drought is an urgent issue, providing objective and timely information for managers in mitigating effects of drought.

Traditional methods based on investigation and survey results face many difficulties in monitoring reservoir water surface area variations, especially in cases where the study area is large. Furthermore, the continuous monitoring of changes in the spatial extent and area of water reservoirs necessitates the collection of ongoing monitoring data, which can result in the expenditure of time, resources, and expenses. Remote sensing technology with outstanding advantages such as wide coverage area and short revisiting time has been effectively used in assessing the impact of drought on water resources. The current remote sensing data set is diverse and continuously updated, especially free remote sensing data such as Landsat and Sentinel multispectral images, allowing effective monitoring of changes in the area of reservoirs.

Surface water can be clearly distinguished from other land cover objects due to the difference in spectral reflectance characteristics in the visible and infrared wavebands (Xiao et al., 2002). 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 extracting surface water from optical satellite images have been proposed, such as using the results of overlay classification (Klemas, 2009;

Shen and Li, 2010), using image ratios (Winarso and Budhiman, 2001; Alesheikh et al., 2006) and water indices. Based on analyzing spectral reflectance characteristics, many scientists have proposed water indices for quick extraction of surface water mantle from optical remote sensing images. These include the Normalized Difference Water Index (NDWI) (Gao, 1996; McFeeters, 1996); Modified Normalized Difference Water Index (MNDWI) (Xu, 2006), Land Surface Water Index (LSWI) (Chandrasekar et al., 2008), Automated Water Extraction Index (AWEI) (Feyisa et al., 2004). These water indexes are widely used in many research services to evaluate changes in surface water area as well as changes in riverbank and coastline (Zhai et al., 2015; Pekel et al., 2016; Liu et al., 2017; Vanderhoof et al., 2018; Lu et al., 2020). The water index is also commonly used in studies in Vietnam to extract water surface information, then vectorize or threshold to create shorelines and assess shoreline changes from multi-temporal remote sensing data. space (Phan et al., 2013; Nguyen and Nguyen, 2016; Trinh et al., 2020). Remote sensing data is also used in studies (Duong et al., 2014; Do et al., 2017; Trinh and Vu, 2019) to build a drought-level partition map using drought indices, providing information for assessing the effects of drought on crops and water resources.

Besides optical remote sensing data, radar images such as Sentinel 1 are also used effectively in extracting surface water cover (Huang et al., 2018). The flat-water surface is characterized by low radar backscatter in SAR images (Kim et al., 2021). This feature allows easy extraction of water bodies from radar images to monitor changes in surface water area.

Additionally, global-scale datasets and cloud computing platforms are now available for large-scale problems such as drought. Multi-temporal Landsat satellite data have been used to produce a global surface water product (Pekel et al., 2016). Google Earth Engine (GEE), a cloud computing platform that provides huge remote sensing image data sets, has been widely used in large-scale and long-term surface water change monitoring tasks (Chen and Zhao, 2022). The analysis of the above studies shows that remote sensing technology is an appropriate and effective tool for monitoring and monitoring the water surface area of reservoirs, especially in conditions of profound influence by drought and climate change.

2. Material and methods

2.1. Study area and materials

2.1.1. Study area

The study area in this paper is Daklak province, Central Highlands region (Vietnam). This is one of the most severe drought areas in Vietnam, leading to a huge decrease in surface water resources during the dry season. 03 large reservoirs in Daklak province, including including Ea Sup Thuong Lake (Ea Sup district), Ea Uy Lake and Krong Buk Ha Lake (Krong Pak district) were selected to evaluate the change in water surface area in the dry season in early 2020. The geographical location map of the study area is shown in Figure 1.

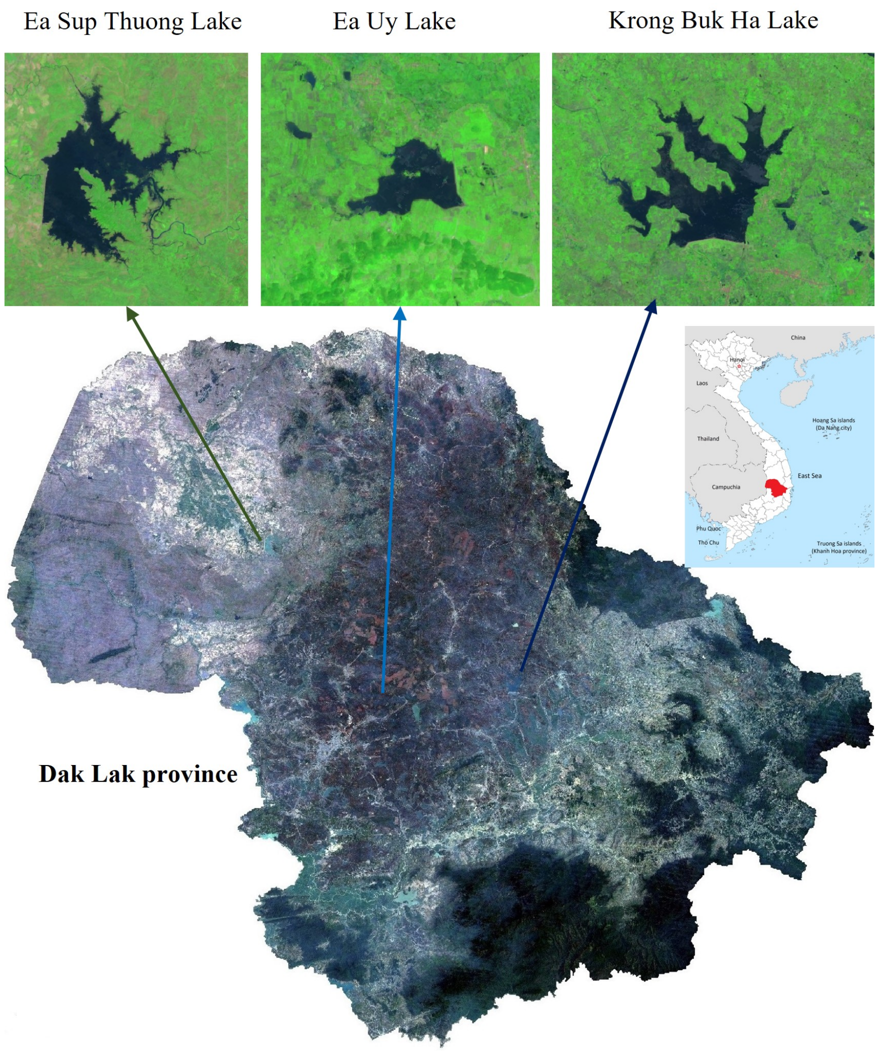

Fig. 1. The study area

2.1.2. Materials

Remote sensing data used in the study includes Sentinel 2A and Sentinel 2B images in the dry season in early 2020, including January, February, March, April and May 2020 images in Dak Lak province. Sentinel 2 images taken in November and December were not used in the study because there was no significant difference in the water surface area reservoirs compared with those taken in January. The collected images are of good quality and unaffected by clouds. Therefore, images may be collected at different times between lakes. The collection process is done through the Copernicus database (https://scihub.copernicus.eu/dhus/#/home).

Sentinel 2 MSI images were collected at L2A processing level, which was corrected for radiation and returned to the spectral reflectance value. Images after downloading from the Copernicus database are geometrically corrected to eliminate errors in the shape and position of the image. After preprocessing, Sentinel 2 MSI image data is color-combined and cropped according to the study area.

After passing through the atmosphere to the Earth's surface the electromagnetic radiation will interact with objects on the Earth's surface. Different objects will have different spectral reflectance characteristics. Spectral reflectance characteristics are very important information to help classify objects on optical remote sensing images, including surface water mantle.

Water has low spectral reflectance compared to other objects such as plants and soil and tends to decrease with increasing wavelength (Govender et al., 2007). In the near-infrared and infrared wavelengths, water absorbs most of the incident electromagnetic radiation energy, so the reflected energy will be very little. On image bands in this range, the water is almost black and clearly distinguishable from other objects.

Green band (band 3) and short-wave infrared band (band 11) are used to extract water surface areas from images using MNDWI index. The input image data in the Ea Sup Thuong Lake (Ea Sup district), Ea Uy Lake, and Krong Buk Ha Lake (Krong Pak district) in natural color combination are presented in Figures 2–4.

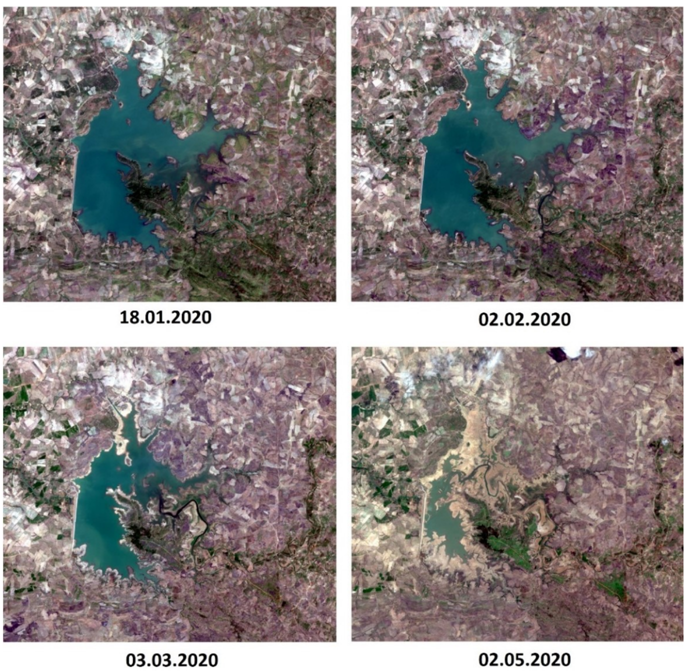

Fig. 2. MSI Sentinel 2 image in Ea Sup Thuong Lake area

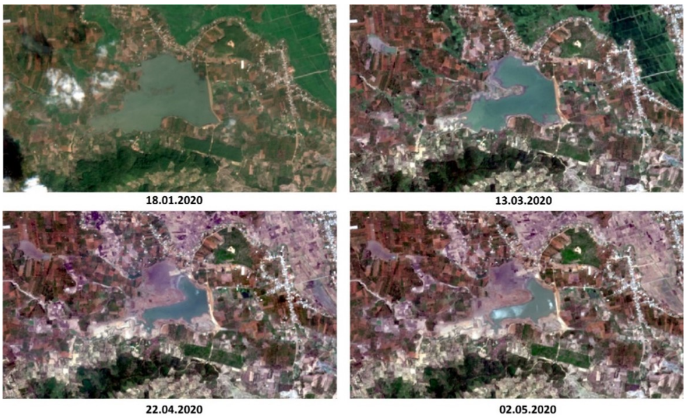

Fig. 3. MSI Sentinel 2 image in Ea Uy Lake area

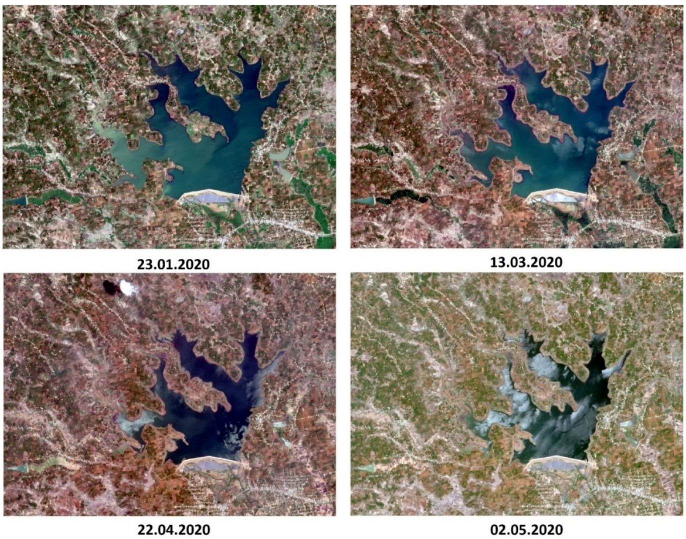

Fig. 4. MSI Sentinel 2 image in Krong Buk Ha Lake area

2.2. Methodology

To evaluate the change in water surface area of reservoirs in the study area, the adjusted water difference index MNDWI is used to extract surface water objects based on the thresholding method. The Modified Normalized Difference Water Index (MNDWI) was proposed by Xu (2006) based on assessing the advantages and limitations of the NDWI index. To calculate the MNDWI index, the spectral reflectance value at the green band and the short-wave infrared ($SWIR_1$) are used according to the following formula:

$$\mathrm{MNDWI} = \frac{\mathrm{GREEN} - \mathrm{SWIR}_1}{\mathrm{GREEN} + \mathrm{SWIR}_1}. \tag{1}$$

For the Sentinel 2 MSI image, these spectral bands correspond to band 3 (green, spatial resolution 10 m) and band 11 ($SWIR_1$, spatial resolution 20 m). Based on the histogram of the MNDWI water index image, the researchers selected a threshold to classify the water and non-water classes. This threshold value is included in the classification, the smaller value pixels are brought to the non-water layer, otherwise, they will belong to the water layer. The errors of overfitting and omission are calculated to find the optimal threshold (Hawkins, 2004). Deciding which threshold is optimal will be based on the error of overfitting and the error of omission. If the error of overfitting is large, the error of omission will be small and vice versa. Therefore, the optimal threshold will give the classification result with the error of overfitting equal to the error of omission.

The results of extracting water surface area information on the basis of MNDWI index from multi-time Sentinel 2 MSI satellite images are used to evaluate the change in the area of water reservoirs under the impact of drought in the study area. The process of building changes in water surface area of reservoirs map is done on ArcGIS 10 software. Sentinel 2 MSI satellite image data processing is done with the help of ERDAS Imagine 2014. The flow chart of the evaluation process of water surface area of reservoirs from Sentinel 2 MSI satellite image is shown in Figure 5.

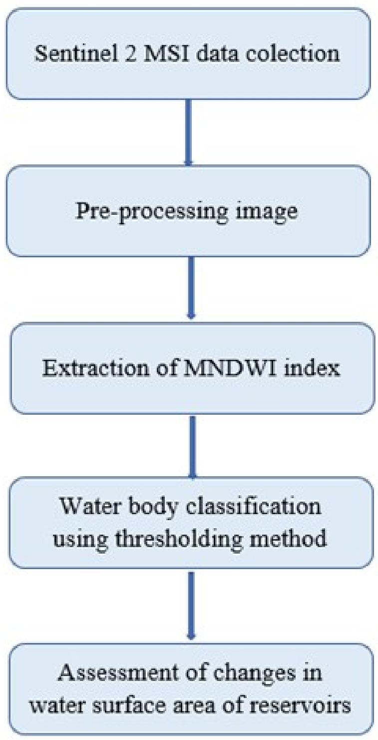

Fig. 5. Water surface area reservoirs changes assessing process from Sentinel 2 MSI image

3. Results

3.1. Ea Sup Thuong Lake

Ea Sup Thuong is the largest artificial freshwater lake in Dak Lak province and the second largest in the Central Highlands (after Lake Ayun Ha – Gia Lai). The lake is located in Chu Ma Lanh commune, Ea Sup district, Dak Lak province and about 7 km west of Ea Sup town. The lake was formed by blocking the Ea Sup stream, which was put into use in 2004 with a water surface area of nearly 1,500 hectares (three times larger than Lak Lake), the water storage capacity can be up to 146 million cubic meters. According to the design, the lake will handle water to irrigate 9,455 hectares of rice along with the area of other crops of 7 communes: Ea Le, Ea Bung, Ea Drong, Ea Roc, Chu Ma Lanh, Ea Lop, Ea Tmot and Thi Thi. Ea Soup town.

The results of determining the MNDWI water index in the Upper Ea Sup Lake area from the Sentinel 2 MSI image in the dry season in early 2020 are shown in Figure 5. The MNDWI index has a value in the range from -1 to 1, in which water is represented by light-colored pixels, while land is dark. As can be seen in Figure 6, the water surface area of Thuong Ea Sup Lake has decreased greatly in May 2020 compared to January 2020. The accuracy of surface water extraction results of Upper Ea Sup Lake area by thresholding method is over 91% for all 04 Sentinel 2 MSI images.

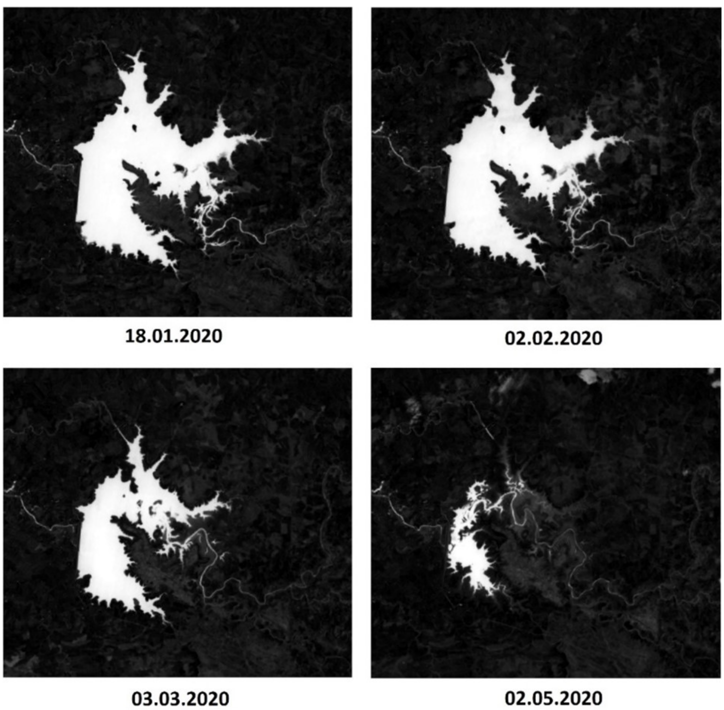

Fig. 6. NDVI index determined from Sentinel 2 MSI image of Ea Sup Lake area

Table 1 shows the value of the MNDWI index determined from the Sentinel 2 MSI satellite image of the Upper Ea Sup Lake area in the dry season in early 2020 and the threshold value for water object separation.

Table 1. Value of MNDWI index in Upper Ea Sup Lake area

MNDWI	18-01-2020	02-02-2020	13-03-2020	02-05-2020
Max	0.931	0.794	0.866	0.753
Min	–0.584	–0.549	–0.679	–0.550
Threshold	0.009	0.001	0.004	–0.008

The results of extraction of surface water area of Upper Ea Sup Lake area in the dry season in early 2020 including 04 scenes on January 18, 2020, February 2, 2020, March 3, 2020 and May 2, 2020 superimposed to compare and evaluate the change in water surface area (Fig. 7). Analysis of the received results showed that, in January 2020, the water surface area of Ea Sup Thuong Lake reached 1368.80 hectares, then decreased continuously in the months of February 2020 (1279.71 hectares), March 2020 (986.98 hectares) and May 2020 (231.72 hectares). Thus, compared to the beginning of the dry season (January 2020), at the end of the dry season (May 2020), the water surface area of Thuong Ea Sup Lake is reduced by nearly 6 times. This change is very clearly shown in Figure 6, in which the lake's surface area in May 2020 is depicted in red, while the water surface area in January 2020 is represented by the blue.

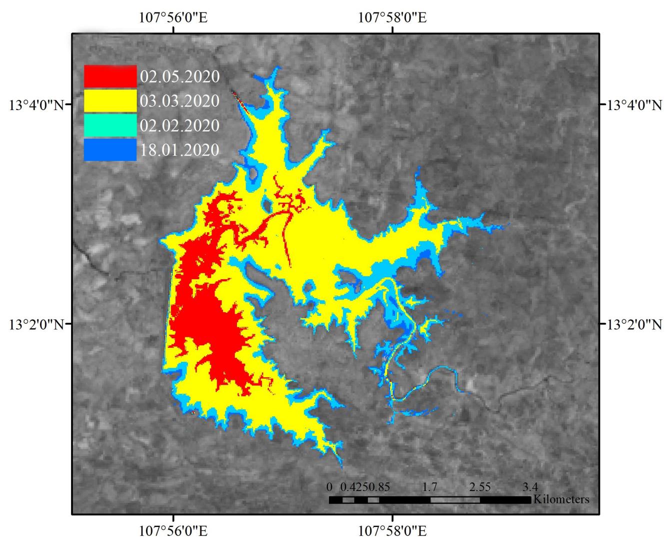

Fig. 7. Changes in surface water of Upper Ea Sup Lake

3.2. Ea Uy Lake

Ea Uy Lake is a large water reservoir located in Krong Pak district, Dak Lak province. The lake has important values in terms of irrigation and fisheries as well as providing a source of domestic water for the locality.

To evaluate the change in water surface area of Lake Eau during the dry season in early 2020, in the study 04 Sentinel 2 MSI images were used, including images taken on January 18, 2020, March 13, 2020. 04/2020 and 02/05/2020. The results of calculating the MNDWI water index from 04 Sentinel 2 images of the Lake Eau area are presented in Figure 8.

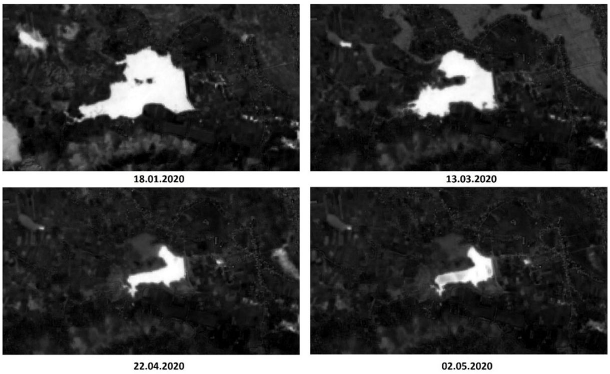

Fig. 8. The NDVI index determined from the Sentinel 2 MSI image of the Ea Uy

Table 2 shows the value of the MNDWI index determined from the Sentinel 2 MSI satellite image of the Ea Uy Lake area in the dry season in early 2020.

Table 2. Value of MNDWI index in Ea Uy Lake area

MNDWI	18-01-2020	13-03-2020	22-04-2020	02-05-2020
Max	0.776	0.819	0.688	0.729
Min	–0.449	–0.502	–0.491	–0.516
Threshold	0.001	–0.004	–0.005	–0.007

Similar to the area of Upper Ea Sup Lake, the study also used the thresholding method to extract surface water objects from the MNDWI index (accuracy over 90%), then superimposed to evaluate the change in surface water. The results of the superposition of the lake surface area from 04 Sentinel 2 MSI images in the dry season in early 2020are shown in Figure 9, in which the water surface of Lake Eau in January 2020 is shown in blue, March 2020 by light blue, April 2020 by yellow and May 2020 represented by red.

Analysis of the obtained results shows that the water surface area of Ea Uy Lake also has a continuous decrease in the dry season in early 2020, of which the corresponding gain is 97.72 hectares (January 2020), 71,47 hectares (March 2020), 27,18 hectares (April 2020) and 24.49 hectares (May 2020). Thus, compared with the beginning of the dry season (January 2020), at the end of the dry season 2019 – 2020 (May 2020), the water surface area of Ea Uy Lake has decreased by about 4 times.

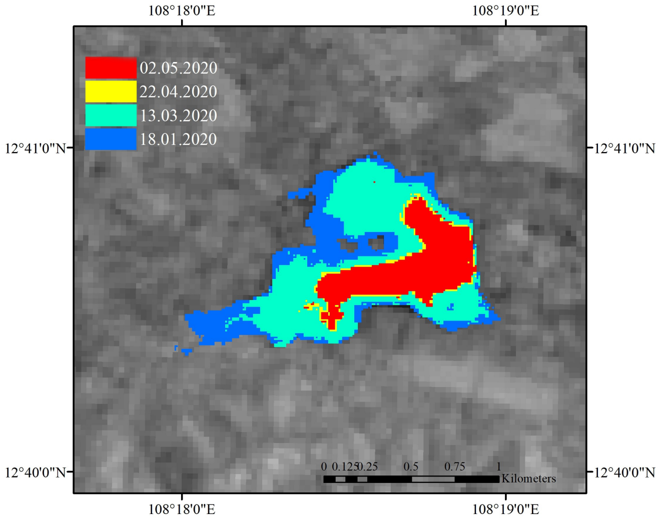

Fig. 9. Changes in surface water area of Ea Uy Lake

3.3. Krong Buk Ha Lake

The lake is located about 40 km from Buon Ma Thuot city center, in the east of Dak Lak province, in Ea Phe commune, Krong Pak district. The reservoir has a capacity of nearly 110 million m^3 of water, the capacity of irrigating 11,400 ha of all kinds of crops, providing water for 72,000 households; at the same time, it has the effect of preventing annual floods in the downstream area, aquaculture and improving the environmental landscape. for Krong Pac district and part of Ea Kar district.

Figure 10 shows the results of calculating the MNDWI water index in the Krong Buk Ha Lake area from the Sentinel 2 MSI images taken on January 23, 2020, March 13, 2020, April 22, 2020 and May 2, 2020. It can be seen that in May 2020, the water surface area of Krong Buk Ha Lake had a significant decrease compared to the first period of the dry season (January 2020). Based on MNDWI water index, the surface water objects were also extracted by thresholding method. For Krong Buk Ha Lake area, the accuracy of surface water object extraction results by thresholding method is over 92% for all 04 Sentinel 2 MSI image scenes.

Table 3 shows the value of the MNDWI index determined from the Sentinel 2 MSI satellite image of the Krong Buk Ha Lake area in the dry season in early 2020.

Figure 11 shows the results of assessing the change in the water surface area of Krong Buk Ha Lake (Krong Pak district) in the dry season in early 2020. It can be seen that the water surface area of Krong Buk Ha Lake also has a continuously decrease in the dry season in early 2020, but it is lower than that of Ea Uy and Upper Ea Sup. In January 2020, the water surface area of Krong Buk Ha Lake reached 1096.26 hectares. By March 2020, the water surface area of Krong Buk Ha Lake decreased to 929.02 hectares and continued to decrease to 822.32 hectares (in April 2020), May 2020 (790.25 hectares). Thus, compared with the beginning of the dry season, at the end of the dry season, the water surface area of Krong Buk Ha Lake decreased by about 28%.

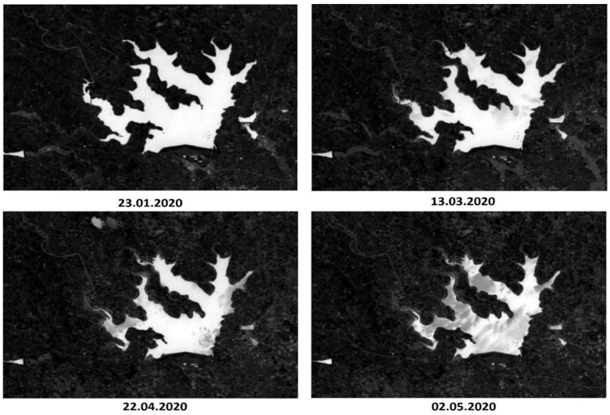

Fig. 10. NDVI index determined from Sentinel 2 MSI image of Krong Buk Ha Lake

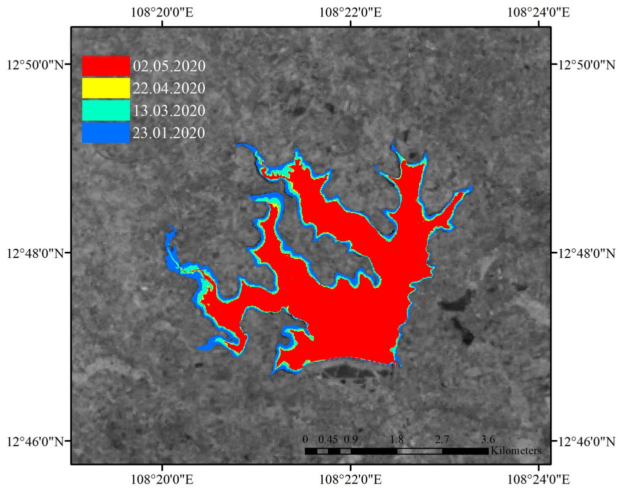

Fig. 11. Variation of surface water area of Krong Buk Ha Lake

Table 3. Value of MNDWI index in Krong Buk Ha Lake area

MNDWI	23-01-2020	13-03-2020	22-04-2020	02-05-2020
Max	0.902	0.889	0.795	0.776
Min	–0.584	–0.595	–0.530	–0.559
Threshold	0.014	0.007	–0.005	–0.017

4. Conclusions

In this study, the change in water surface area of 03 reservoirs in Dak Lak province, including Ea Sup Thuong reservoirs (Ea Sup district), Ea Uy and Krong Buk Ha reservoirs (Krong Pak district) was conducted from satellite images Sentinel 2 MSI optical crystallizer for the dry season period early 2020. For each reservoir, 04 Sentinel 2 MSI images from January 2020 to May 2020 were used to extract the water surface area of the lakes on the basis of MNDWI water index, then superimposed to compare and evaluate the change in water surface area of reservoirs. The obtained results show that the water surface area of all 03 reservoirs has decreased continuously in the dry season 2019 – 2020, in which the water surface area of Ea Sup Thuong reservoir (Ea Sup district) decreased about 6 times in the end of the dry season (May 2020) compared to the beginning of the dry season (January 2020). With the area of Ea Uy Lake (Krong Pak district), the rate of decline is about 4 times. Meanwhile, with Krong Buk Ha Lake, the decrease in surface water area is lower, reaching about 28% at the end of the dry season compared to the beginning of the dry season in early 2020.

The results obtained in the study can provide overview information about the status of water resources in the region, helping managers in monitor and assess the impact of drought on water resources, thereby taking timely measures to minimize the impact of drought as well as sustainably use surface water resources in the study area.

Author contributions

Conceptualization: L.H.T; methodology: L.H.T, X.B.T; formal analysis and investigation: L.H.T, K.H.D.; writing – original draft preparation: L.H.T.; writing – review and editing: K.H.D.; supervision: L.H.T., X.B.T.

Data availability statement

The datasets used during the current study are available from the corresponding author on reasonable request.

Acknowledgements

No funding was obtained for this study.

References

Alesheikh, A., Ghorbanali, A., and Nouri, N. (2007). Coastline change detection using remote sensing. *Int. J. Environ. Sci. Tech.*, 4(1), 61–66. DOI: 10.1007/BF03325962.

Chen, Z., and Zhao, S. (2022). Automatic monitoring of surface water dynamics using Sentinel-1 and Sentinel-2 data with Google Earth Engine. *Int. J. Appl. Earth Obs. Geoinf.,* 103010. DOI: 10.1016/j.jag.2022.103010.

Do, T.N.A., Nguyen, Q.P., and Nguyen, H.S. (2017). Research methods agricutural drought warning in downstream of Ca River. *J. Wat. Resour. Environ. Eng.*, 56, 24–33.

Duong, V.K., Nguyen, H.Q., Tran, T.T. et al. (2013). Application of remote sensing technology to assess the severity of drought in Central coastal area of Vietnam. *Vietnam J. Hydrometeo.*, 2, 26–32.

Feyisa, G., Meiby, H., Fensholt, R. et al. (2014). Automated water extraction index: A new technique for surface water mapping using Landsat imagery. *Remote Sens. Environ.*, 140, 23–35. DOI: 10.1016/j.rse.2013.08.029.

Gao, B.C. (1996). NDWI – A normalized difference water index for remote sensing of vegetation liquid water from space. *Remote Sens. Environ.*, 58, 257–266. DOI: 10.1016/S0034-4257(96)00067-3.

Govender, M., Chetty, K., and Bulcock, H. (2007). A review of hyperspectral remote sensing and its application in vegetation and water resource studies. *Wat.*, 33(2), DOI: 10.4314/wsa.v33i2.49049.

Hawkins, D.M. (2004). The problem of overfitting. *J. Chem. Inf. Comp. Sci.*, *44*(1), 1–12. DOI: 10.1021/ci0342472.

Huang, W., DeVries, B., Huang, C. et al. (2018). Automated Extraction of Surface Water Extent from Sentinel-1 Data. *Remote Sens.* 10, 797. DOI: 10.3390/rs10050797.

Ishikawa-Ishiwata, Y., and Furuya, J. (2022). *Economic evaluation and climate change adaptation measures for rice production in Vietnam using a supply and demand model: special emphasis on the Mekong River delta region in Vietnam*. In: Ito T., Tamura M., Kotera A., Ishikawa-Ishiwata Y. (eds) Interlocal Adaptations to Climate Change in East and Southeast Asia. SpringerBriefs in Climate Studies, Springer: Cham. DOI: 10.1007/978-3-030-81207-2_4.

Kim, D., Moon, W., Kim, G. et al. (2011). Submarine groundwater discharge in tidal flats revealed by space-borne synthetic aperture radar. *Remote Sens. Environ.*, 115(2), 793–800. DOI: 10.1016/j.rse.2010.11.009.

Klemas, V. (2009). The role of remote sensing in predicting and determining coastal storm impacts. *J. Coast. Res.*, 25(6), 1264–1275. DOI: 10.2112/08-1146.1.

Le, T., Sun, C., Choy, S. et al. (2021). Regional drought risk assessment in the Central Highlands and the South of Vietnam. *Geomat. Nat. Haz. Risk*, 12(1), 3140–3159. DOI: 10.1080/19475705.2021.1998232.

Liu, Y., Wang X., Ling F. et al. (2017). Analysis of coastline extraction from Landsat-8 OLI imagery. *Wat.*, 9(11), 816. DOI: 10.3390/w9110816.

Lu, X., Yang, K., Lu, Y. et al. (2020). Small Arctic rivers mapped from Sentinel-2 satellite imagery and ArcticDEM. *J. Hydro.*, 584, 124689. DOI: 10.1016/j.jhydrol.2020.124689.

McFeeters, S.K. (1996). The use of normalized difference water index (NDWI) in the delineation of open water features. *Int. J. Remote Sens.*, 17, 1425–1432. DOI: 10.1080/01431169608948714.

Nguyen, V.T., and Nguyen, V.K. (2016). Monitoring coastline changes using landsat multi-temporal data in the Cua Dai estuary, Thu Bon River, Quang Nam. *J. Mining Earth Sci.*, 57, 81–89.

Pekel, J.F., Cottam, A., Gorelick, N., Belward, A.S. (2016). High-resolution mapping of global surface water and its long-term changes. *Nat.,* 540 (7633), 418–422. DOI: 10.1038/nature20584.

Phan, K.D., Vo, Q.M., Nguyen, T.H.D. et al. (2013). Evaluation of landslide and accretion in coastal areas of Ca Mau and Bac Lieu provinces from 1995 to 2010 using remote sensing and GIS technology. *Can Tho Uninersity J. Sci.*, 26, 35–43.

Schmidt-Thome, P., Nguyen, T.H., Pham, T.L. et al. (2014). Climate change adaptation measures in Vietnam, Development and Implementation. *SpringerBriefs in Earth Sci.* DOI: 10.1007/978-3-319-12346-2.

Shen, L., and Li, C. (2010). Water body extraction from Landsat ETM+ imagery using adaboost algorithm. *In Proceedings of the 18th International Conference on Geoinformatics*, Beijing, China, 18-20 June 2010, 1–4.

Thenkabail, P.S., Gamage, M.S., and Smakhtin, V.U. (2004). The use of remote sensing data for drought assessment and monitoring in southwest Asia. Res. Rep., 85, International Water Management Institute, 34.

Trinh, L.H., and Vu, D.T. (2019). Application of remote sensing technique for drought assessment based on normalized difference drought index, a case study of Bac Binh district, Binh Thuan province (Vietnam). *Russian J. Earth Sci.*, 19, ES2003, 1–9. DOI: 10.2205/2018ES000647.

Trinh, L.H., Le, T.G., Kieu, V.H. et al. (2020). Application of remote sensing technique for shoreline change detection in Ninh Binh and Nam Dinh provinces (Vietnam) during the period 1988 to 2018 based on water indices. *Russian J. Earth Sci.*, 20, ES2004, 1–15. DOI: 10.2205/2020ES000686.

Vanderhoof, M.K., Lane, C.R., McManus, M.G. et al. (2018). Wetlands inform how climate extremes influence surface water expansion and contraction. *Hydrol. Earth Syst. Sci.*, 22(3), 1851–1873. DOI: 10.5194/hess-22-1851-2018.

Vu, T.H., Ngo, D.T., and Phan, V.T. (2014). Evolution of meteorological drought characteristics in Vietnam during the 1961–2007 period. *Theor. Appl. Clim.*, 118, 367–375. DOI: 10.1007/s00704-013-1073-z.

Winarso, G., and Budhiman, S. (2001). The potential application of remote sensing data for coastal study. In Proc. 22nd. Asian Conference on Remote Sensing, Singapore.

Xiao, X., Boles, S., Frolking, S. et al. (2002). Observation of flooding and rice transplanting of paddy rice fields at the site to landscape scales in China using VEGETATION sensor data. *Int. J. Remote Sens.*, 23(15), 3009–3022. DOI: 10.1080/01431160110107734.

Xu, H. (2006). Modification of normalized difference water index (NDWI) to enhance open water features in remotely sensed imagery. *Int. J. Remote Sens.*, 27(14), 3025–3033. DOI: 10.1080/01431160600589179.

Zhai, K., Wu, X., Qin, Y., Du, P. et al. (2015). Comparison of surface water extraction performances of different classic water indices using OLI and TM imageries in different situations. *Geospatial Inf. Sci.*, 18(1), 32–42. DOI: 10.1080/10095020.2015.1017911.