INTERNATIONAL CONFERENCE GIS-IDEAS 2023

PROCEEDINGS

Geospatial Integrated Technologies for Natural Hazards and Environmental Problems

HUNRE, Ha Noi, Viet Nam

07-09 November 2023

PUBLISHING HOUSE FOR SCIENCE AND TECHNOLOGY

INTERNATIONALCONFERENCE

GEOSPATIAL INTEGRATED TECHNOLOGIES FOR NATURAL HAZARDS AND ENVIRONMENTAL PROBLEMS

PUBLISHING HOUSE FOR SCIENCE AND TECHNOLOGY
HA NOI - 2023

Organized by

Hanoi University of Natural Resources and Environment (HUNRE)
Osaka Metropolitan University (OMU)
The Japan - Viet Nam Geoinformatics Consortium (JVGC)

Co-organizers

Hanoi University of Mining and Geology (Vietnam)
Japan Geotechnical Consultant Association
Japan Society of Geoinformatics

With the support and collaboration of

Department of National Remote Sensing (Vietnam)
Department of Survey, Mapping and Geographic Information (Vietnam)
Ho Chi Minh University of Natural Resources and Environment (Vietnam)
National Centre for Hydro-Meteorological Forecasting (Vietnam)
Vietnam Institute of Geosciences and Mineral Resources
Institute of Resources Geography, Ho Chi Minh (Vietnam)
Vietnam Disaster and Dyke Management Authority
Ho Chi Minh City Space Technology Application Center (Vietnam)
Institute of Marine Geology and Geophysics (Vietnam)
Nong Lam University, Ho Chi Minh (Vietnam)
NextTech Group of Technopreneurs (Vietnam)
Vietnam National University, Hanoi
Vietnam Academy for Water Resources
Vietnam National Forestry University
Association of Vietnam Geographers
Military Technology Academy (Vietnam)
Asian Institute of Technology (Thailand)
Naresuan University (Thailand)
Thuy Loi University (Vietnam)
University of Phayao (Thailand)
Everest Schools (Vietnam)

CONFERENCE FOUNDERS

Late Prof. Takashi FUJITA (Japan)

Dr. Nghiem Vu KHAI (Vietnam)

SYMPOSIUM CHAIRS

Prof. Dr. Huynh Thi Lan HUONG (Vietnam)

Prof. Venkatesh RAGHAVAN (Japan)

ORGANIZING SECRETARIES

Assoc. Prof. Dr. Le Thi TRINH (Vietnam)

Dr. Go Yonezawa (Japan)

CONFERENCE COORDINATORS

Ms. Tanyaluck CHANSOMBAT (Thailand)

Dr. Tatsuya NEMOTO (Japan)

Ms. Vu Thi Thuy NGAN (Vietnam)

Dr. Truong Xuan QUANG (Vietnam)

STEERING COMMITTEE

Dr. Ho Dinh DUAN (Vietnam)

Dr. Duong Van HAI (Vietnam)

Prof. Dr. Tran Thanh HAI (Vietnam)

Assoc. Prof. Hoang Anh HUY (Vietnam)

Dr. Mai Van KHIEM (Vietnam)

Prof. Yasuyuki KONO (Japan)

Prof. Nguyen Kim LOI (Vietnam)

Prof. Truong Xuan LUAN (Vietnam)

Prof. Shinji MASUMOTO (Japan)

Prof. Alaa A MASOUD (Egypt)

Prof. Muneki MITAMURA (Japan)

Dr. Doan Thi Tuyet NGA (Vietnam)

Dr. Lam Dao NGUYEN (Vietnam)

Assoc. Prof. Huynh QUYEN (Vietnam)

Dr. Trinh Hai SON (Vietnam)

Assoc. Prof. Nguyen Canh THAI (Vietnam)

Prof. Nitin TRIPATHI (Thailand)

Dr. Chu Hai TUNG (Vietnam)

Prof. Yasushi YAMAGUCHI (Japan)

WORKSHOP COMMITTEE

DAO Hoang Tung (Vietnam)

Natraj VADDADI (India)

SCIENTIFIC COMMITTEE

TABLE OF CONTENT

MONITORING SURFACE WATER BODIES CHANGES FROM SENTINEL-2A IMAGERY WITH MODIFIED NORMALIZED DIFFERENCE WATER INDEX: APPLICATION IN DALAT, LAM DONG, VIET NAM

Trung Van Nguyen [1,2]*, Ha Thu Thi Le[1,2]

[1]Faculty of Geomatics and Land Administration,
Hanoi University of Mining and Geology, Vietnam
[2]Geomatics in Earth Sciences Research Group,
Hanoi University of Mining and Geology, Vietnam
*Corresponding author. Email: nguyenvantrung@humg.edu.vn

ABSTRACT

Accurately monitoring open water bodies is a fundamental and crucial task in remote sensing. Numerous techniques for mapping water bodies have been devised to extract them from multi-spectral images. One of the most widely used techniques is the method relying on the spectral water index, particularly the Modified Normalized Difference Water Index (MDNWI), which is derived from the green and Shortwave-Infrared (SWIR) bands. The purpose of the study is to identify surface water body changes using Sentinel-2 MSI (Multi-Spectral Instrument) data, one of the latest types of remote sensing satellite data. The results of the research show that by using Sentinel-2 MSI imagery, MNDWI (Modified Normalized Water Index) is the appropriate parameter to detect surface water areas in the studied area, with an overall accuracy > 0.92 and Kappa coefficient > 0.84. Additional research is required, specifically targeting diverse geographical conditions and exploring other regions within Vietnam.

1. INTRODUCTION

Monitoring surface water body changes has a great significance in understanding hydrology processes and managing water resources (Roberts et al., 1993; Vorosmarty et al., 1997; Papa et al., 2008). Recently, remote sensing has become a suitable approach for monitoring surface water body changes because the acquired data can provide real-time, dynamic and cost-effective information, which is substantially different from conventional *in situ* measurements (Chen et al., 2004; Du et al., 2011; and Feng et al., 2012). There were various methods developed in order to extract water bodies from different remote sensing images, include single band density slicing (Work and Gilmer, 1976), unsupervised and supervised classification (Sivanpillai et al., 2010; and Huang et al., 2014ab) and spectral water indexes (Hui et al., 2008; Li et al., 2013; Du et al., 2014; Xie et al., 2014; Jiang et al., 2014; Mizuochi et al., 2014; Yao et al., 2015; and Li et al., 2016). To select the water body mapping methods, the spectral water index-based method is chosen because it is efficient and has low computational cost (Ryu et al., 2002). In the past several decades, the Normalized Difference Water Index (NDWI) was proposed by McFeeters, 1996, using the green and Near Infrared (NIR) bands of remote sensing images relied on strong absorbability and low radiation of the water bodies in the range from visible to infrared wavelengths. In most cases, the water information is effectively enhanced by using NDWI. However, it is sensitive to built-up land. To overcome the foible of NDWI, Xu, (2006) developed the Modified Normalized Difference Water Index (MNDWI) (Xu et al., 2006) that uses the Shortwave Infrared (SWIR) band instead of the NIR band used in NDWI. Many previous research works have demonstrated that MNDWI is more suitable to extract water bodies with greater accuracy than NDWI (Xu et al., 2006; Li et al., 2013; Du et al., 2014; Singh et al., 2015).

More recently, MNDWI has been widely applied to produce water body maps at different scales. In practice, the spatial resolutions of both the SWIR and green bands directly affect the accuracy of mapped water bodies. For instance, MODerate-resolution Imaging Spectroradiometer (MODIS) images at 250-m spatial resolution have been popularly used to generate water bodies at both global and regional scales (Caroll et al., 2009; Huang et al., 2012). For regional studies, images at 30-m spatial resolution provided by the Thematic Mapper (TM), the Enhanced Thematic Mapper Plus (ETM+) and the latest Operational Land Imager (OLI) from Landsat series satellites are relevant datasets (Hui et al., 2008; Du et al., 2014; and Rokni et al., 2014). Although the Landsat TM, ETM+ and OLI images can extract water bodies with more accurate boundaries, the spatial resolution of Landsat series images is still not good enough to detect smaller-sized open water bodies, such as narrow gutters and small pools in urban areas. By rapid development of remote sensing data consisting of SPOT6/7, IKONOS and Quick-bird having spatial resolution under 1-m, these small-sized water bodies can be monitored. However, these very high spatial resolution images have no SWIR band, making it impossible to use the MNDWI method.

For convenience, the European Space Agency (ESA) launched a new Sentinel-2 satellite on 23 June 2015. The Sentinel-2 images can provide for regional water body's maps due to their reasonable properties (*i.e.*, the 10-m spatial resolution for four bands and the 10-day revisit frequency) and the free access. The Sentinel-2 carries the Multi-spectral Imager (MSI). This sensor has a total of 13 spectral bands, in which four bands (blue, green, red and NIR) have a spatial resolution of 10 m and six bands (including the SWIR band) have a spatial resolution of 20 m. Since the green and SWIR bands are included, the MNDWI method gathers water bodies from the Sentinel-2 images. The objectives of this study are to (1) produce MNDWI from the Sentinel-2 image by the green and the SWIR bands; (2) use the produced MNDWI to extract water bodies; and (3) evaluate the map-level accuracy of the resultant water body map.

2. STUDY AREA & DATA SET

2.1 Study Area

Da Lat city is situated on the Lam Vien plateau, serving as the administrative center of Lam Dong province. It is approximately 300 kilometers to the northeast of Ho Chi Minh city, 110 kilometers west of Phan Rang and 130 kilometers to the northeast of Nha Trang. Da Lat holds a central role in Lam Dong province, serving as its political, administrative, economic, cultural and service hub. It also plays a crucial role as a significant economic trading center and a focal point for various forms of tourism, particularly sightseeing tours, resorts, conferences, seminars and ecological activities within the country and the surrounding region. Furthermore, it stands as one of the nation's primary institutions for diverse education and advanced scientific research.

Despite the limited availability of surface water resources in Da Lat, they are sufficient to cater to the socio-economic needs of a city primarily oriented toward tourism, services, education and scientific research. The primary preference for sourcing water remains surface water, with underground water reserved for use in suburban residential areas only when centralized water supply systems are absent. Although the water quality in several significant reservoirs such as Dan Kia, Suoi Vang, Tuyen Lam, Chien Thang and Da Thien remains favorable at present, it is essential to maintain a long-term focus on protective measures to reduce the risk of pollution and sedimentation. (Figure 1).

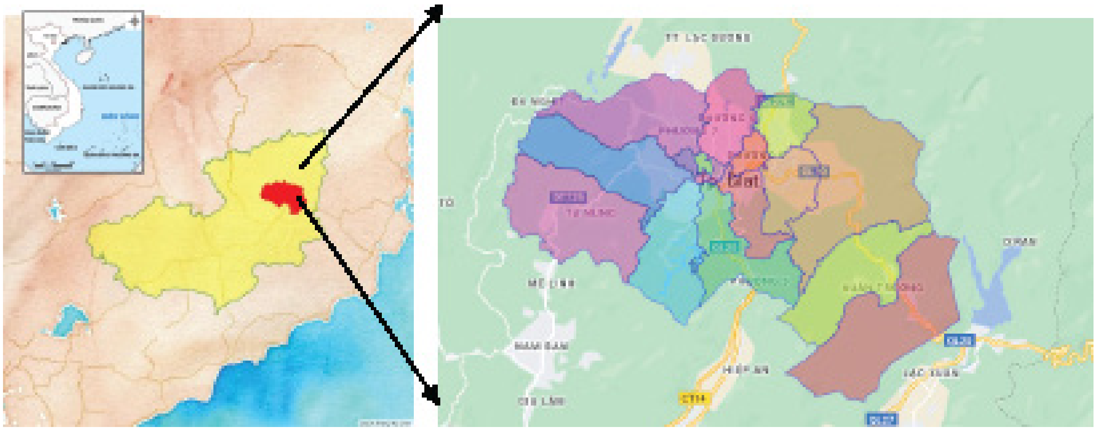
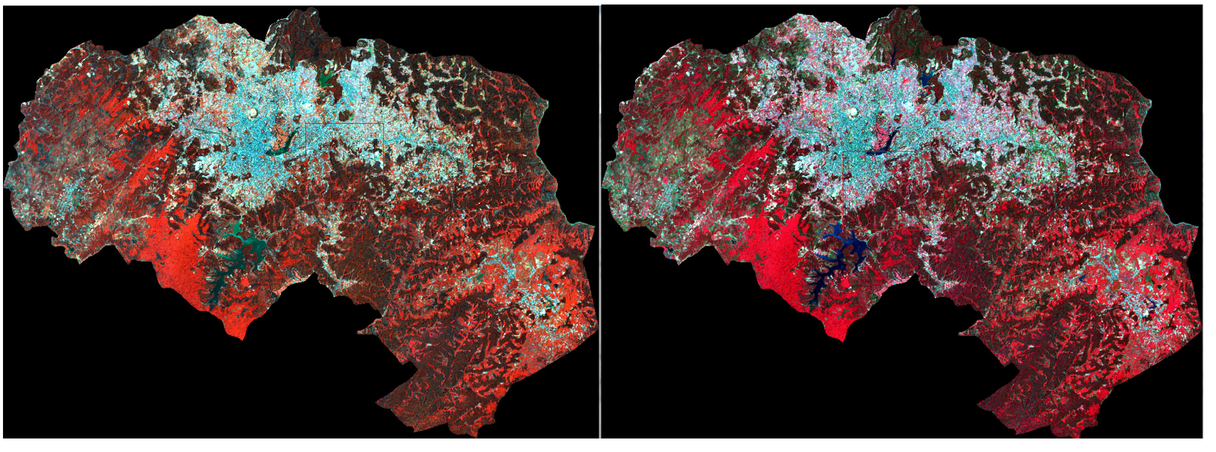


Figure 1. The study area.

https://bandovietnam.com.vn/ban-do-thanh-pho-da-lat

2.2 Data set

In this research, time series of Sentinel-2A (Level_2A) images with a cloud cover of less than 1 % have been used. The reason for the very low cloud coverage is that in the continuation of the classification process, we need to obtain the area of the water class in each image. For this reason, the presence of clouds can create many problems in our calculations.



(a) ***(b)***

Figure 2. Satellite images cut by the boundaries of Dalat city on the dry (a) and the flood season (b).

Table 1. Acquisition date of the Sentinel-2A satellite images used during 2022 in Dalat city.

Number	Sensing Date	Mission
1	12 March 2022	Sentinel-2A

Number	Sensing Date	Mission
2	18 November 2022	Sentinel-2A

Sentinel-2 is an Earth observation mission developed by ESA as part of the Copernicus Program to carry out ground-based observations in support of services such as forest monitoring, land area change detection and disaster management. It consists of two identical satellites built by Airbus DS, Sentinel-2A and Sentinel-2B.

The Sentinel-2 mission has the following capabilities:

• Multi-spectral data with 13 bands in the visible, near-infrared, infrared and shortwave portions of the spectrum;

• Systematic global coverage of land surfaces from 56°S to 84°N, coastal areas and all of the Mediterranean Sea;

• Repeat every 5 days under the same view. Sentinel-2 repeat shooting cycle will be shorter than 5 days at high latitudes or shooting with different viewing angles;

• Spatial resolution of 10 m, 20 m and 60 m;

• The scanning range is 290 km wide;

• Free and open data policy.

3. METHODOLOGY

Figure 3 shows the flowchart of the implemented method for the detection and analysis of the change in bodies of water in two seasons. Our research consists of three main steps: (1) Selection of bands and indicators of water body extraction, (2) Surveying thresholds of water index to classify the images into two water and non-water classes and (3) Analysis and interpretation of changes.

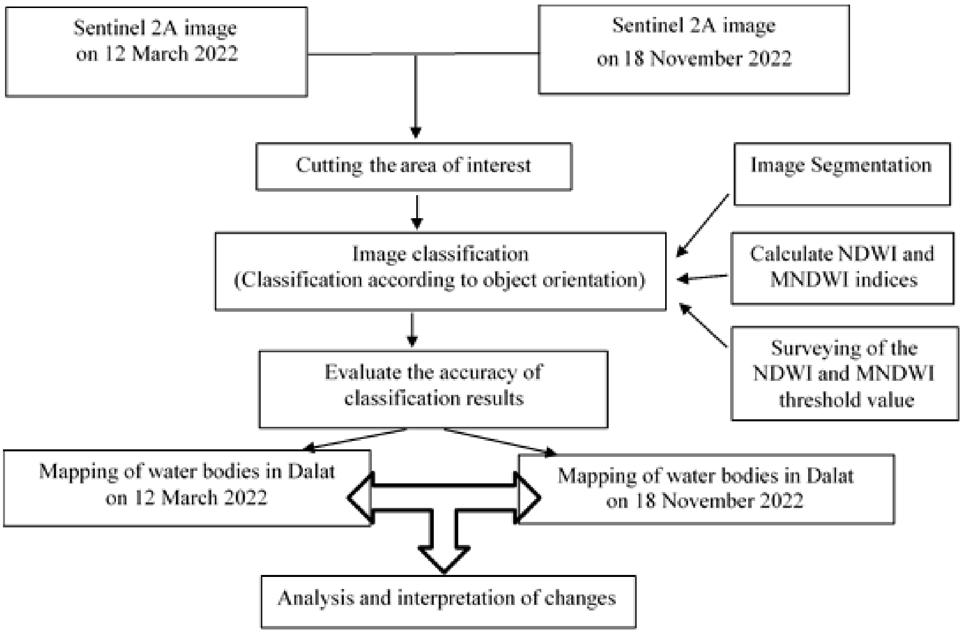


Figure 3. Flowchart of the implemented method for detection and analysis of the change in bodies of water in two seasons.

4. RESULTS

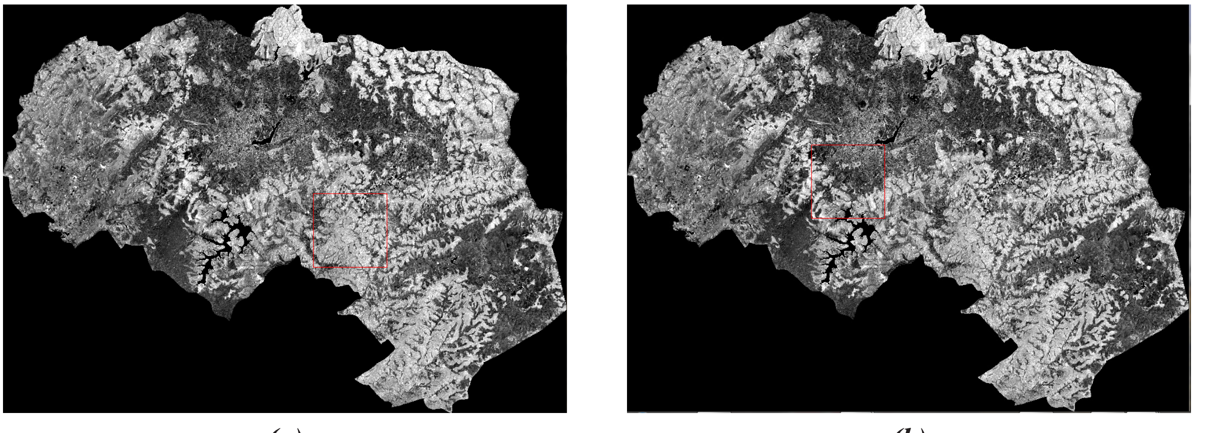
4.1 Results of surface water extraction using the MNDWI index method

A positive value in the NDWI index signifies the presence of surface water, making it a valuable tool for identifying and assessing alterations in surface water coverage. The NDWI index, as introduced by McFeeters, strives to (a) enhance the reflectivity of surface waters in the green band and (b) diminish the reflectivity of surface waters in the near-infrared (NIR) band, as expressed by the following formula:

$$NDWI = \frac{\rho_{Green} - \rho_{NIR}}{\rho_{Green} + \rho_{NIR}} \quad (1)$$

For Sentinel 2A images, the NDWI index is determined as follows:

$$NDWI = \frac{\rho_{Band\ 3} - \rho_{Band\ 8}}{\rho_{Band\ 3} + \rho_{Band\ 8}} \quad (2)$$



(a) ***(b)***

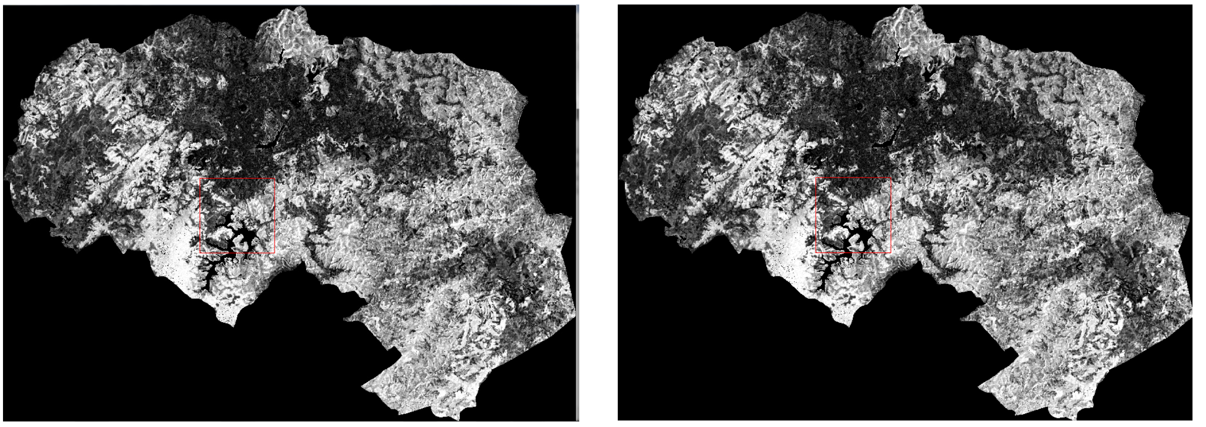
Figure 4. The NDWI index image outcomes within Da Lat City on the dry (a) and the flood season (b).

4.2 Results of surface water extraction using the MNDWI index method

One significant drawback of the NDWI index is its tendency to be mistaken for built-up areas. Xu et al., (2006) identified that it's possible to differentiate between surface water areas and built-up regions by examining the short wavelength infrared (SWIR) band. Consequently, the MNDWI index is introduced and calculated as follows:

$$MNDWI = \frac{\rho_{Green} - \rho_{SWIR}}{\rho_{Green} + \rho_{SWIR}} \quad (3)$$

For Sentinel 2A images, the MNDWI index is determined as follows:



(a) *(b)*

Figure 5. The MNDWI index image outcomes within the Da Lat city on the dry (a) and the flood season (b).

Following the generation of the NDWI and MNDWI index images, surface water bodies are identified through a thresholding process. Typically, NDWI and MNDWI index values fall within the range of [-1, 1], with 0 serving as the commonly used threshold to differentiate between water and non-water.

In this research, both NDWI and MNDWI indices were computed. The study employed these indices to extract surface water features, selecting the suitable water separation index for each type of surface water resource.

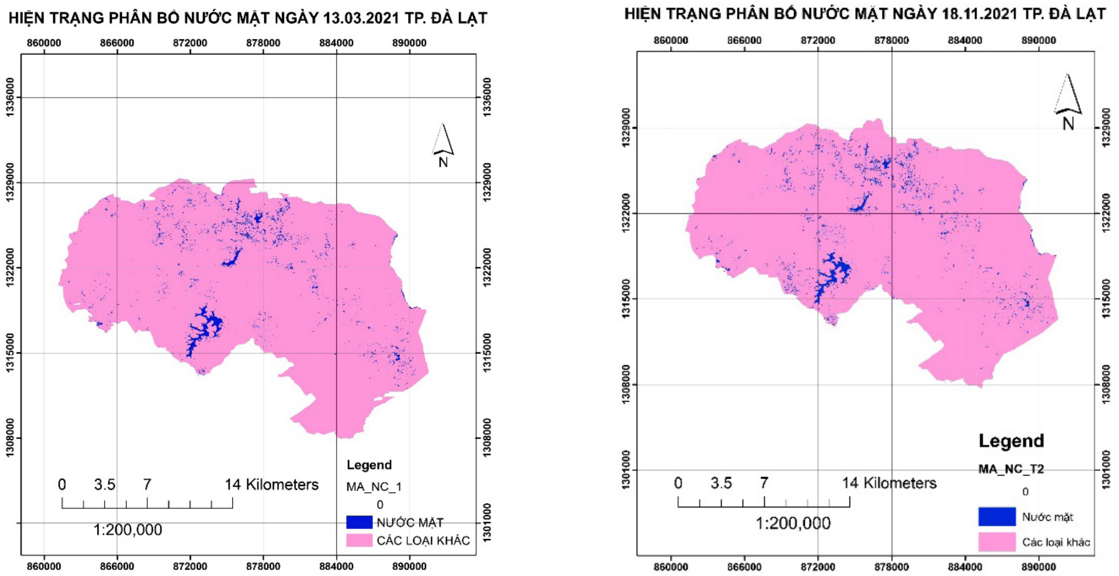
4.3 Evaluate the accuracy of classification results

The accuracy of the extracted current surface water distribution from two sets of Sentinel 2A satellite images was assessed using a combination of direct surveys conducted on the 1-meter spatial resolution satellite images.

Random control samples were taken across the entire study area, totaling 80 regions encompassing two surface types (water and others). These regions were subsequently overlaid with high-resolution satellite image data from 2022 to calculate statistics measuring the actual level of correspondence between objects. The Kappa coefficient, calculated according to Congalton's formula, revealed that the classification accuracy of the 2022 surface water distribution based on the MNDWI index image was 94.07 %, which matches the current classification accuracy of 94.07 %. In contrast, the accuracy for the surface water distribution status in 2022 derived from the NDWI index image was 88.64 %.

Consequently, this study opted for MNDWI index images to extract surface water information, confirming their suitability for characterizing the distribution of surface water resources within the project's study area.

4.4 The findings from evaluating the present state of surface water distribution within the city of Da Lat, encompassing two distinct research periods



(a) *(b)*

Figure 6. Results of surface water extraction from Sentinel 2A satellite images in Da Lat City on the dry (a) and the flood season (b).

Table 2. Statistics on surface water area for two periods, March and November 2022, in Dalat city.

Land cover	12 March 2022 (ha)	18 November 2022 (ha)	Change (ha)
1-Water	691,430	759,939	+ 68.51
2-Non-water	38,768.330	759,939	- 68.51
Total (ha)	39,459.760	39,459.760	0

Examining the outcomes regarding the spatial distribution of surface water resources in Da Lat city within Lam Dong province, in conjunction with the statistical data, it becomes evident that Da Lat encompasses surface water resources that make up nearly 2 % of the city's total area. These resources are primarily in the form of rivers, streams and lakes, with a predominant concentration in the form of large lakes such as Xuan Huong, Than Tho and Tuyen Lam.

Simultaneously, over the past two decades, the sectors of agriculture, tourism and population have all experienced significant growth. Consequently, Da Lat city finds itself in need of pragmatic water management solutions. This is especially critical to safeguard the purity of the surface water environment, as it plays a pivotal role in preserving the aesthetics necessary for tourism development and is closely linked to the well-being of the local population.

5. DISCUSSION

Da Lat's flow pattern is contingent upon the climate and can be categorized into two distinct seasons: the flood season and the dry season. In May, Da Lat transitions into its rainy season, during which streams that had previously dried up due to the dry period do not initially produce surface runoff; instead, the initial rains are absorbed into the soil. Thanks to its excellent permeability, the streams become inundated, typically occurring 1.5 to 2 months after the onset of the rainy season.

The period spanning from May to July signifies the transitional phase from dry to flood conditions in Da Lat's streams. During this transitional phase, the basin accumulates more moisture, eventually culminating in the flood season in July. This coincides with the heavy and prolonged rainfall that characterizes the rainy season.

The rainy season concludes in November and the transition from the flood season to the dry season is gradual. During this receding phase, stream waters gradually decrease, but significant floods can still occur due to late rains falling on already water-saturated basins. As the transition progresses from flood to dry conditions, groundwater plays a crucial role in moderating stream water levels, reducing the disparity in flow patterns. Effectively, the flood season extends until the end of November.

Throughout the flood season, approximately 70 % of the annual water volume is contained within the streams. The peak flood months typically occur in September and October, contributing to around 20 % of the total annual water volume. Early-season floods are often triggered by thunderstorms, while major floods during the peak flood season result from storms and tropical convergence zones. Late-season floods are usually induced by storms or by heavy rainfall, occasionally.

Once the rainy season concludes, the streams quickly begin to lose water. By the time April arrives, they reach their lowest point, constituting just about 2 % of the total annual water volume. Streams with smaller drainage areas (less than 5 square kilometers) found in the southwest and southeast corners of the city originate from elevated areas that lack forest vegetation cover and possess only a weathered surface layer. Consequently, they frequently run dry and cease to flow.

The contrast in precipitation between the dry and rainy seasons is quite noticeable. Nonetheless, as per the findings detailed in Table 2, the expansion of surface water within Da Lat city has been limited to nearly 70 hectares. This restriction is primarily attributed to the city's steep topography, which impedes the retention of substantial surface water during the rainy season. Therefore, to enable the growth and advancement of high-quality agriculture, alternative water sources or modern water-saving technologies are imperative.

6. CONCLUSION

The investigation involved the extraction of surface water resource data by establishing thresholds for the NDWI and MNDWI indices. The indices derived from Sentinel 2A imagery have demonstrated their efficacy in surface water area analysis. Findings from the study indicate that the utilization of NDWI and MNDWI water extraction indices facilitates a more straightforward separation of surface water entities. This is particularly advantageous when distinguishing water bodies within residential and industrial areas and during construction processes, resulting in increased accuracy in satellite image classification outcomes. Consequently, it can be inferred that optical remote sensing images offer a superior solution for surface water research.

Nonetheless, there exist certain limitations and challenges in terms of data and methodologies that warrant further investigation. To enhance precision and dependability, novel threshold determination techniques may be employed. The crucial aspect of implementing these new thresholding methods, which involve statistical analysis functions, lies in the requirement for significantly larger and more detailed field data. This data should also be collected over an extended timeframe for comparison with specific scenes, enabling the selection of precise thresholds for each distinct research area.

Furthermore, it is imperative to persist in the development of this research avenue and its application within the emerging realm of artificial intelligence and machine learning algorithms. While optical remote sensing image data has proven effective in surface water research, it's essential to acknowledge its primary limitation-vulnerability to cloud cover and adverse weather conditions. This can lead to information gaps or inaccuracies, particularly in Vietnam's mountainous regions. In this regard, radar remote sensing image data emerges as a viable approach for mitigating the influence of clouds and rainfall in surface water research. By amalgamating this data with optical images and incorporating innovative technologies such as drones, a comprehensive solution can be devised for studying and mapping the current status and fluctuations in surface water resources.

7. REFERENCES

Carroll, M. L., Townshend, J. R., DiMiceli, C. M., Noojipady, P., and Sohlberg, R. A., 2009. A new global raster water mask at 250 m resolution. *Int. J. Digit. Earth, 2*, 291-308.

Chen, Q. L., Zhang, Y. Z., Ekroos, A., Hallikainen, M., 2004. The role of remote sensing technology in the EU water framework directive (WFD). *Environ. Sci. Policy, 7*, 267-276.

Du, Y., Xue, H. P., Wu, S. J., Ling, F., Xiao, F., and Wei, X. H., 2011. Lake area changes in the middle Yangtze region of China over the 20th century. *J. Environ. Manag, 92*, 1248-1255.

Du, Z. Q., Li, W. B., Zhou, D. B., Tian, L. Q., Ling, F., Wang, H. L., Gui, Y. M., and Sun, B. Y., 2014. Analysis of Landsat-8 OLI imagery for land surface water mapping. *Remote Sens. Lett., 5*, 672-681.

Feng, L., Hu, C. M., Chen, X. L. Cai, X. B., Tian, L. Q., and Gan, W. X., 2012. Assessment of inundation changes of Poyang Lake using MODIS observations between 2000 and 2010. *Remote Sens. Environ., 121*, 80-92.

Huang, C., Chen, Y., and Wu, J. P., 2014b. Mapping spatio-temporal flood inundation dynamics at large river basin scale using time-series flow data and MODIS imagery. *Int. J. Appl. Earth Obs. Geoinf., 26*, 350-362.

Huang, C., Chen, Y.,and Wu, J. P., 2014a. DEM-based modification of pixel-swapping algorithm for enhancing floodplain inundation mapping. *Int. J. Remote Sens., 35*, 365-381.

Huang, S. F., Li, J. G., and Xu, M., 2012. Water surface variations monitoring and flood hazard analysis in Dongting Lake area using long-term Terra/MODIS data time series. *Nat. Hazards, 62*, 93-100.

Hui, F. M., Xu, B., Huang, H. B., Yu, Q., and Gong, P., 2008. Modelling spatial-temporal change of Poyang Lake using multitemporal Landsat imagery. *Int. J. Remote Sens, 29*, 5767-5784.

Jiang, H., Feng, M., Zhu, Y. Q., Lu, N., Huang, J. X., and Xiao, T., 2014. An automated method for extracting rivers and lakes from landsat imagery. *Remote Sens, 6*, 5067-5089.

Li, W. B., Du, Z. Q., Ling, F., Zhou, D. B., Wang, H. L., Gui, Y. M., Sun, B. Y., and Zhang, X. M., 2013. A comparison of land surface water mapping using the normalized difference water index from TM, ETM plus and ALI. *Remote Sens., 5*, 5530-5549.

Li, W., Qin, Y., Sun, Y., Huang, H., Ling, F., Tian, L., and Ding, Y., 2016. Estimating the relationship between dam water level and surface water area for the Danjiangkou Reservoir using Landsat remote sensing images. *Remote Sens. Lett., 7*, 121-130.

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

Mizuochi, H., Hiyama, T., Ohta, T.,and Nasahara, K. N., 2014. Evaluation of the surface water distribution in north-central namibia based on MODIS and AMSR series. *Remote Sens., 6*, 7660-7682.

Papa, F., Prigent, C., and Rossow, W. B., 2008. Monitoring flood and discharge variations in the large siberian rivers from a multi-satellite technique. *Surv. Geophys., 29*, 297-317.

Roberts, N., Taieb, M., Barker, P., Damnati, B., Icole, M., and Williamson, D., 1993. Timing of the younger dryas event in east-Africa from lake-level changes. *Nature 366*, 146-148.

Rokni, K., Ahmad, A., Selamat, A., and Hazini, S., 2014. Water feature extraction and change detection using multitemporal landsat imagery. *Remote Sens., 6*, 4173-4189.

Ryu, J. H., Won, J. S., and Min, K. D., 2002. Waterline extraction from Landsat TM data in a tidal flat-A case study in Gomso Bay, Korea. *Remote Sens. Environ., 83*, 442-456.

Sheng, Y. W., Shah, C. A., and Smith, L. C., 2008. Automated image registration for hydrologic change detection in the lake-rich Arctic. *IEEE Geosci. Remote Sens. Lett., 5*, 414-418.

Singh, K.V., Setia, R., Sahoo, S., Prasad, A.,and Pateriya, B., 2015. Evaluation of NDWI and MNDWI for assessment of waterlogging by integrating digital elevation model and groundwater level. *Geocarto Int. 30*, 650-661.

Sivanpillai, R.,and Miller, S. N., 2010. Improvements in mapping water bodies using ASTER data. *Ecol. Inform. 5*, 73-78.

Vorosmarty, C. J., Sharma, K. P., Fekete, B. M., Copeland, A. H., Holden, J., Marble, J., and Lough, J. A., 1997. The storage and aging of continental runoff in large reservoir systems of the world. *AMBIO 26*, 210-219.

Work, E. A.,and Gilmer, D. S., 1976. Utilization of satellite data for inventorying prairie ponds and lakes. *Photogramm. Eng. Remote Sens. 42*, 685-694.

Xie, H., Luo, X., Xu, X., Tong, X. H., Jin, Y. M.; Pan, H. Y.,and Zhou, B. Z., 2014. New hyperspectral difference water index for the extraction of urban water bodies by the use of airborne hyperspectral images. *J. Appl. Remote Sens. 8*, 085098.

Xu, H. Q., 2006. Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. *Int. J. Remote Sens. 27*, 3025-3033.

Yao, F. F., Wang, C., Dong, D., Luo, J. C., Shen, Z. F., and Yang, K. H., 2015. High-resolution mapping of urban surface water using ZY-3 multi-spectral imagery. *Remote Sens. 7*, 12336-12355.