Surface Water Monitoring Using GIS and Remote Sensing applications: Case study in Bau Sau, Cat Tien National Park

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Giám sát nước mặt bằng ứng dụng Gis và viễn thám: Trường hợp nghiên cứu tại Bàu Sấu, Vườn Quốc gia Cát Tiên

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ABSTRACT

This study was conducted at Bau Sau, Cat Tien National Park, in Vietnam. Bau Sau is Vietnam's second wetland site out of a total of 9 Ramsar sites that have been recognized by the Ramsar Convention Secretariat in Vietnam. The extraction of surface water is carried out in three methods, including object-based classification and the calculation of NDWI and MNDWI indices. After calculating the overall accuracy of all three methods, the method with the highest percentage will be chosen for extracting the surface water boundary for the study area. With an overall accuracy of 90%, the NDWI index was used for extracting the water surface map in the period 2015–2024. The results also showed that the surface water area in Bau Sau was 42.15 hectares in 2015, 41.89 hectares in 2020, and 41.51 hectares in 2024. The fluctuation in the surface water area during 2015-2024 is clearly visible, showing a decrease of 0.64 hectares. The fluctuation is attributed to the vegetation communities, with the proliferation of Cyperus cephalotes being the most notable. Cat Tien National Park managers need to pay attention and take early measures in the near future to avoid impacting the habitat of some animal species in this area.

***Từ khóa**:*
NDWI và MNDWI, phát hiện biến đổi nước, phân loại theo đối tượng, trích xuất nước mặt, Vườn quốc gia Cát Tiên.

TÓM TẮT

Nghiên cứu này được thực hiện tại Bàu Sấu, Vườn quốc gia Cát Tiên, Việt Nam. Bàu Sấu là khu đất ngập nước thứ hai của Việt Nam trong tổng số 9 khu Ramsar đã được Ban Thư ký Công ước Ramsar tại Việt Nam công nhận. Việc trích xuất được thực hiện theo ba cách, bao gồm phân loại dựa trên đối tượng và tính toán các chỉ số NDWI và MNDWI. Với độ chính xác tổng thể là 90%, chỉ số NDWI được sử dụng để trích xuất bản đồ mặt nước giai đoạn 2015–2024. Kết quả cũng cho thấy diện tích mặt nước ở Bàu Sấu là 42,15 ha vào năm 2015, 41,89 ha vào năm 2020 và 41,51 ha vào năm 2024. Sự biến động về diện tích mặt nước của khu vực nghiên cứu trong giai đoạn này được thể hiện một cách rõ ràng. Việc tính toán diện tích mặt nước trong giai đoạn này cho thấy diện tích đã giảm 0,64 ha. Sự biến động này được cho là do các quần hợp thực vật, trong đó đáng chú ý nhất là sự phát triển của loài cỏ Chấp (Cephalotes Cyperus). Các nhà quản lý Vườn quốc gia Cát Tiên cần quan tâm và có biện pháp xử lý sớm trong thời gian tới để tránh ảnh hưởng đến môi trường sống của một số loài động vật tại khu vực này.

1. INTRODUCTION

Currently, Cat Tien National Park has several wetlands such as: Bau Ca Tre, Bau Tra, Bau Sau, Bau Sen, Bau Ca, Bau Chim, Bau Trau, Bau Dat, Bau Da Mi... and a lowland part of Dak Lua stream [1]. In the rainy season, the ponds have water and some of them are connected to the Dak Lua stream. In the dry season, only a few large ponds have water, the small ponds are dry. In whichs, Bau Sau is a wetland that changes seasonally, so the water surface area fluctuates greatly between the dry and rainy seasons. This wetland ecosystem is a "hotspot" of biodiversity with 250 species of floating

plants, 56 species of animals, 88 species of Fish, 23 species of Frogs, 45 species of Reptiles, 154 species of Birds, 34 species of mammals [1]. This place has high value in terms of biodiversity, environment, landscape and tourism.

However, Bau Sau is currently facing challenges of climate change. Especially the adverse impacts on biodiversity and changes in the flooded area of Bau Sau. Climate change changes a number of factors such as rain, sunshine, humidity, wind, storms... especially the frequency and duration of major floods and droughts, which will reduce biological productivity. In fact, in Bau Sau, the most obvious changes of climate change affect wetlands due to the strong growth of invasive species such as *Imperata cylindrica*, *Cyperus cephalotes, Eichhornia crassipes*… [2]. They narrow the habitat, living space for native species, and reduce the surface area of water.

Currently, there are many methods of applying technology in detecting changes in surface water areas of areas over time such as GIS, remote sensing, UAVs, ground-based sensors, etc. GIS is a powerful technology that integrates spatial data, such as maps, satellite imagery, and geospatial information, with attribute data to enable spatial analysis, modeling, and visualization [3]. The application of GIS in water bodies monitoring has significantly advanced our ability to collect, analyze, and interpret data related to water resources [4]. In recent years, several works have harnessed the rising number of free, high spatial and temporal resolution imagery from passive and active sensors, mapping and monitoring small water bodies [5-8], lakes, floodplains and wetlands [9-11]. Numerous methods for extracting water features from satellite data have been introduced through various image processing techniques [12-14].

Due to its numerous and extensive benefits, research on the use of remote sensing and GIS technology to monitor shoreline changes has been ongoing in Vietnam for a long time [15-20]. The main method used is a combination of natural colors and a combination of false colors to distinguish land and water. For this purpose, the Modification of Normalized Difference Water Index (MNDWI) has been widely used in the world [21] and in Vietnam also. In case study in Quang Ninh – Vietnam, Nguyen Hai Hoa and co-authors used both MNDWI and NDVI (Normalized Difference Water Index) indexes for detecting the significant change of water surface with positive values of these have indicated that there is the existence of surface water [22].

This study aims to answer 3 questions (i) Which method is most suitable to determine water surface boundaries (ii) What is the trend of changing water surface area, and (iii) What is the cause of the change?

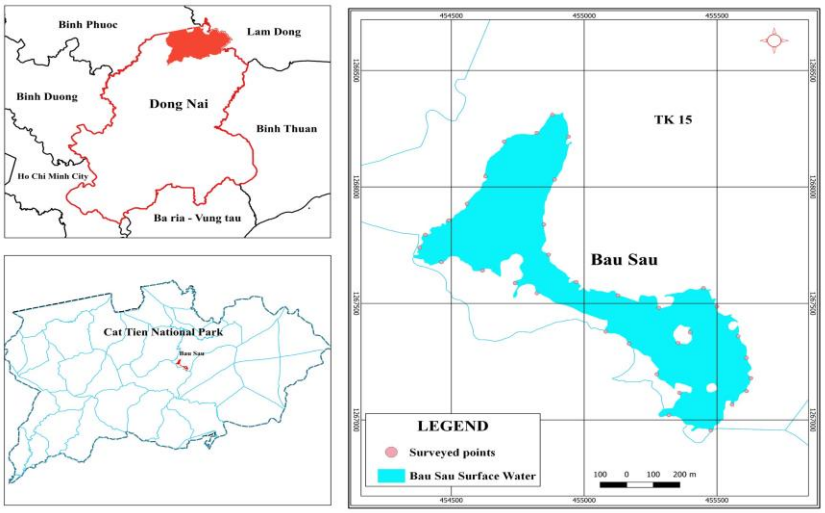


Figure 1. Location of the study area (Bau Sau, Cat Tien National Park, Vietnam)

2. RESEARCH METHODS

2.1. Data set

Five bands of each Landsat 8 data acquired in 2015 and 2020 (in dry season) and five bands of Landsat 9 data acquired in 2024 were used in this research. These data were downloaded from web site earthexplore.usgs.org. Table 1 presents the specifications of Landsat data used in this study.

Table 1. Specifications of Landsat data used in this study

Satellite	Acquisition Date	Resolution (m)	Wavelength (lm)
Landsat 8 TM 2015	06/03/2015	30	Band 2 Blue (0.450 - 0.51 µm) Band 3 Green (0.53 - 0.59 µm) Band 4 Red (0.64 - 0.67 µm) Band 5 Near-Infrared (0.85 - 0.88 µm) Band 6 SWIR (1.57 - 1.65 µm)
Landsat 8 TM 2020	03/03/2020	30	
Landsat 9 TM 2024	19/2/2024	30	

Source: website earthexplore.usgs.org

(a) 2015 *(b) 2020* *(c) 2024*

Figure 2. Landsat Band combination results (Natural color RGB – 4,3,2)

2.2. Method

2.2.1. Feild survey method

A total of 50 survey points have been positioned by the GPS 64 Garmin device used to sample the water surface image as interpretation key. At these points, information on coordinate system, ground-truth pictures, and plant species close to the boundary of surface water.

Based on the initial interviewi nformation from forest rangers in Cat Tien National park, a field survey was conducted using the transect method. This transect was surounding wetland area in Bau Sau. The information about coordinates, elevation, name of tree species, plant growth & development and ecological succession was collected. Plant species names are determined by comparative morphological method.

2.2.2. Data analysis method

The data analysis method this study was illustrated by figure 3.

*** Images Pre-processing**

This process is carried out on ArcGIS software with Raster Calculator tool to convert the grayscale values of Landsat 8 images into radiance and reflectance values. Then use the Composite bands tool to combine colors to create a multispectral image. The Create Pan – Sharpened Raster Dataset tool is used to merge a panchromatic image with a multispectral image to enhance the spatial resolution of the multispectral image.

*** Images processing**

Object based classification

The multi-segmentation technique is utilized to fragment the images by selecting weights depending on several factors such as

shape, compactness, smoothness, and size [23]. The combination of wet soil and wet surface regions need careful consideration when choosing parameters for image fragmentation. The following group is used as the starting point for selecting the parameter group for investigation in this study: 50 is the scale parameter, 0.75 is the shape parameter, and 0.5 is the compactness value. These parameters are then adjusted many times. In the end, we selected the following group: Scale parameter: 10; shape parameter: 0.5; compactness: 0.5 for the purpose of extracting the water's surface in Bau Sau, Cat Tien National Park in 2024. A total of 50 survey points have been positioned by a GPS device used to sample the water surface image as interpretation key. At these points, information on coordinate system, ground-truth pictures, and plant species close to the boundary of surface water.

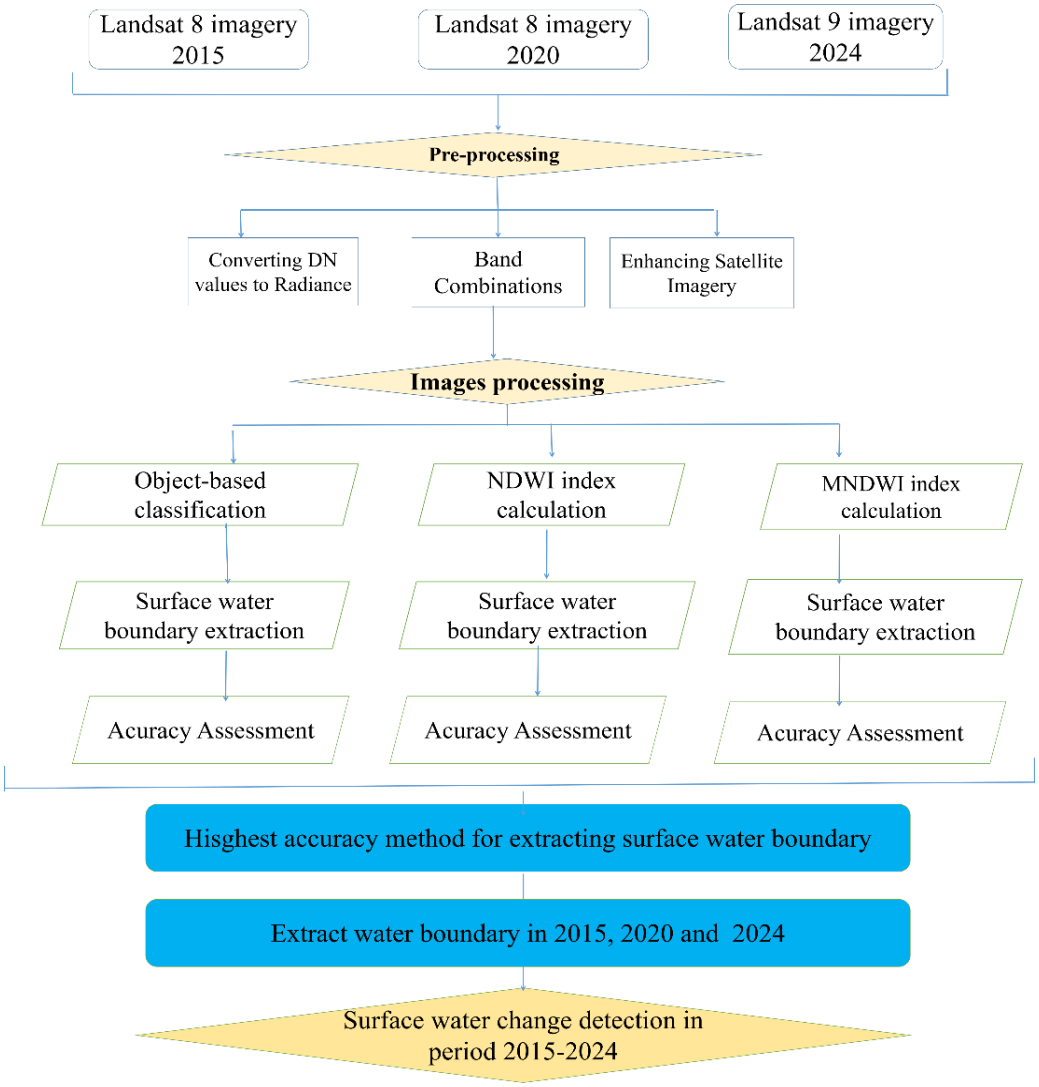


Figure 3. Flow chart of methodology used in the research

NDWI and MNDWI indices calculation

After synthesis and study of relevant documents, two indices NDWI and MNDWI were used to extract the water surface of Bau Sau in 2024 [12, 21, 22]. The application of these indices in extracting water surface has high accuracy, suitable for the research object and provides a reliable scientific basis for related studies.

Table 2. Satellite-derived indices used for surface water extraction

No	Index	Formula	Remark
1	Normalized difference water index	NDWI = (Green – NIR)/ (Green + NIR)	Water has positive value [21]
2	Modified normalized difference water index	MNDWI = (Green – SWIR)/ (Green + SWIR)	Water has positive value [12]

Accuracy assessment

One major issue in accurately assessing the results of change detection is the absence of a reliable ground-truth reference. In order to get over that restriction, data from interviews and some supplied by Cat Tien National Park administration were used to create a map of surface water in 2024 and also the map of water surface changing from 2015 to 2024. The threshold method [24] was used to derive the best threshold to separate water and non-water pixels in the differenced image of NDWI and MNDWI in 2024.

For the accuracy assessment of burned area detection based on the error matrix [25], ground truths on the real water boundary is necessary. The data collected from 50 points in study area were used to calculate the overall accuracy and kappa accuracy.

Water boundary Change detection

Arctoolbox was used to overlay water boundary map in for detecting the changes from 2015 to 2020. For the stage from 2020 to 2024, the process was performed as the same steps. And the area of surface water also was calculated in each year.

3. RESULTS AND DISCUSSION

3.1. Determination of surface water boundaries using different methods

3.1.1. By object-based classification

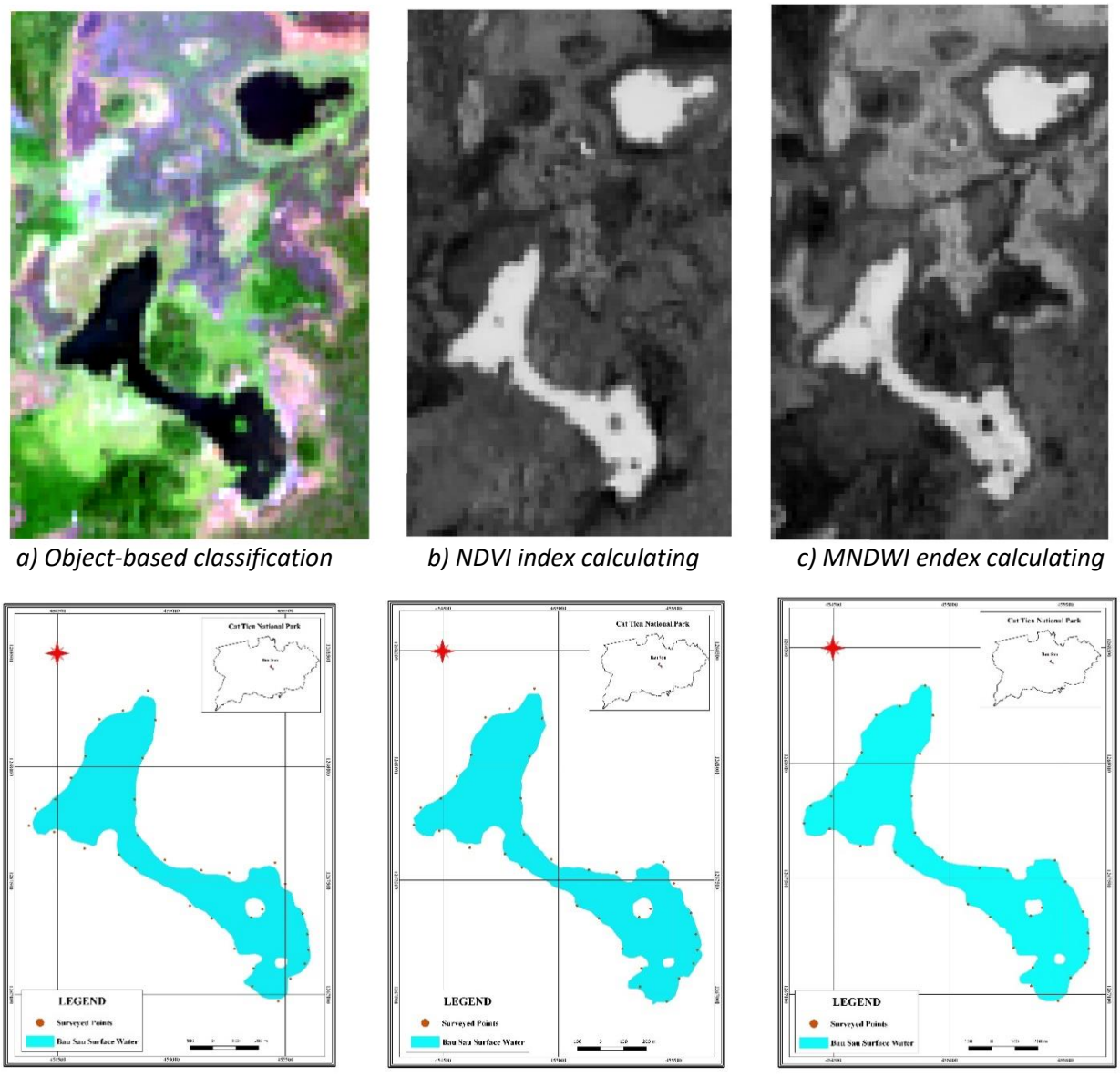
The results of extracting the water surface by object-based classification and calculating the accuracy are shown in Table 3 and Figure 4.

Table 3. Accuracy assessment analysis of Object-based classification

Map / Field	Water	Other objects	Total
Water	26	4	30
Other objects	3	17	20
Total	29	21	50
Overall accuracy		**86.0%**	

For the object-based classification method, after segmenting the image on the Trimble's Ecognition software, a key interpretation model of the image is built based on actual survey data to determine the objects as water bodies and other objects. The result produces a map of surface water boundary in Bau Sau with an area of 43.57 ha (Figure 4a, 4d). Object-based classification takes into account not only pixel-level information but also spatial relationships between neighboring pixels. This allows for the incorporation of contextual information, such as shape, size, and texture, which can improve the accuracy of water boundary extraction. Reduction of spectral confusion: Water bodies can exhibit varying spectral characteristics due to factors like depth, turbidity, and vegetation cover. Object-based classification can help mitigate spectral confusion by considering multiple spectral bands and incorporating ancillary data, such as elevation or vegetation indices. This can improve the discrimination of water bodies from other land cover types. However, the accuracy of object-based classification heavily relies on the quality of object delineation

during the segmentation process. Determining the optimal scale or parameters for segmentation can be subjective and may require trial-and-error or expert knowledge. Incorrect or inconsistent segmentation can affect the accuracy of the final classification results. The accuracy of the Bau Sau surface water map after classification reaches 86% (Table 3).



a) Object-based classification *b) NDVI index calculating* *c) MNDWI endex calculating*

d) Water surface map extracting by Object-based classification *e) Water surface map extracting by NDWI index* *f) Water surface map extracting by MNDWI index*

Figure 4. Water surface boundary extraction by Object-based classification, NDVI index and MNDWI index calculation

3.1.2. NDWI and MNDWI index culculation

The selected indices for extracting the surface water of Bau Sau are NDWI and MNDWI. The water surface area in 2024 estimated using the selected image-specific thresholds. The results of multiple experiments on ArcGIS software and also consultations based on some documents provided by the Cat Tien National Park and the responsible officials in the area show that both NDWI and MNDWI indices have positive values, indicating that the object is water. This is quite consistent with the number of studies by authors [8, 26]. NDWI is less affected by the presence of vegetation

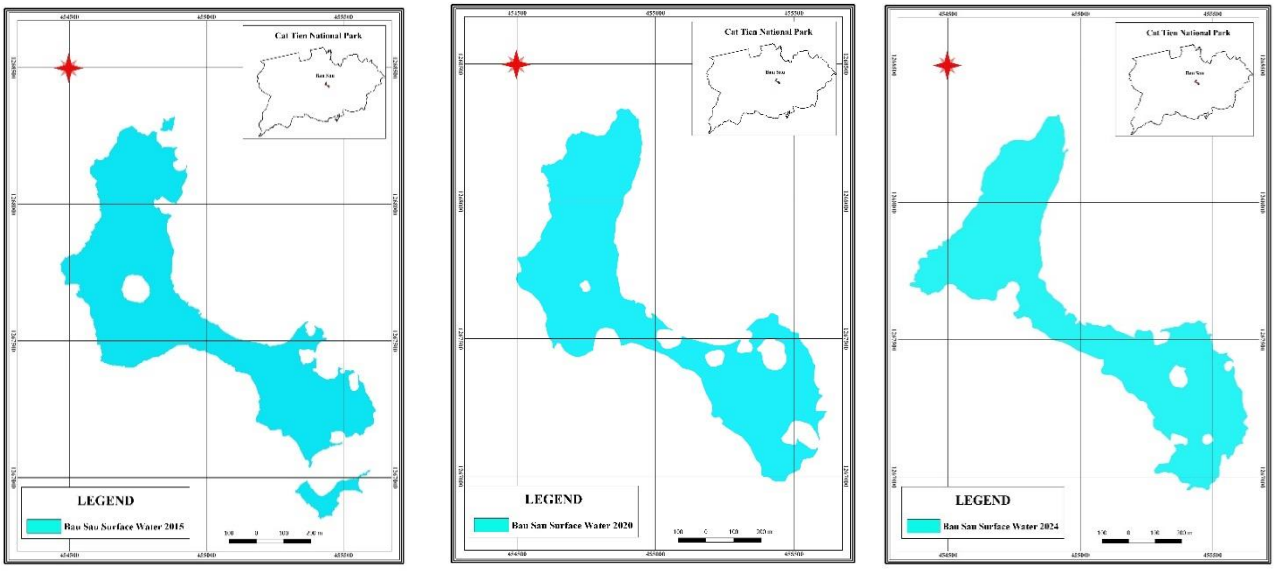
compared to other indices like Normalized Difference Vegetation Index (NDVI). This advantage allows for more accurate water boundary delineation, even in areas with dense vegetation cover. While MNDWI is a modification of NDWI that uses the green and mid-infrared (MIR) bands. By utilizing the MIR band, MNDWI enhances the contrast between open water bodies and other features like built-up areas or bare soil. This increased sensitivity to open water can be particularly beneficial when distinguishing water bodies from urban or arid landscapes. And further analysis results show that the area with higher NDWI and MNDWI values corresponds to a greater water depth at that location.

Table 4. Accuracy assessment analysis of Water surface boundary extraction by NDWI and MNDWI

NDWI index				MNDWI index			
Map / Field	Water	Other objects	Total	Map / Field	Water	Other objects	Total
Water	27	3	30	**Water**	25	5	30
Other objects	2	18	20	**Other objects**	3	17	20
Total	29	21	50	**Total**	28	22	50
Overall accuracy		**90%**		**Overall accuracy**		**84%**	

According to the accuracy assessment analyses of using NDWI and MNDWI indices for extracting surface water in Bau Sau, overall Accuracy of using were 90% and 84% respectively. The results indicate the superiority and higher performance of the NDWI as compared with other index and object-based classification method for the extraction of surface water from Landsat data. For this purpose, the NDWI was calculated from the multi-temporal Landsat imagery in 2015 and 2020. Through the use of specific threshold for NDWI image classification, the surface water boundary area for each year was determined. Ultimately, the maps of surface water area were superimposed to provide a picture of changes in Bau Sau from 2015 to 2024.

3.2. Changes in surface water area in Bau Sau in the period 2015 – 2024



(a) water surface area in 2015 *(b) water surface area in 2020* *(c) water surface area in 2024*

Figure 5. Surface water area maps

The results of building a map using the NDWI index to separate surface water objects and other objects are shown in Figure 5. The surface water area was about 42.15 ha in 2015, 41.89 ha in 2020 and 51.51 ha in 2024. Using the overlay tool in ArcGIS software to detect changes in the water boundary, the results are illustrated in Figure 6. The change can be clearly seen from 2015 to 2024. The water area decreased by 0.64 ha. Specifically, from 2015 to 2020 it decreased by 0.26 ha and from 2020 to 2024, it decreased by 0.38 ha (Table 5).

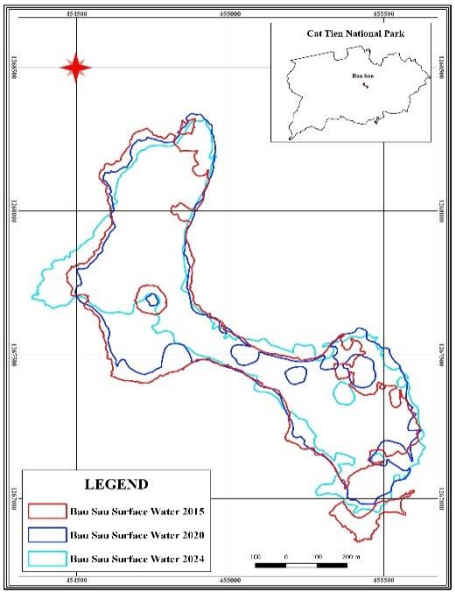


Figure 6. Bau Sau surface water area changes map in the period 2015 – 2024

Table 5. Statistics of surface water area change in Bau Sau from 2015 to 2024

No	Year	Surface water area (ha)	Surface water area change (ha)	Total area change (ha)
1	2015	42.15	- 0.26	-0.64
2	2020	41.89	- 0.38	
3	2024	42.37		

According to the fiel survey in Bau Sau, this wetland is facing many challenges due to natural and man-made factors inluding extreme weather changes such as droughts in the dry season and floods in the rainy season. A total 13 plant associations have been identified and described inluding: *Cyperus cephalotes, Imperata cylindrica, Stenochlaena palustris, Utricularia aurea, Pseudoraphis brunoniana, Eichhornia crassipes, Nymphoides indica, Ludwigia adscendens, Persicaria hydropiper, Panicum repens, Mimosa pigra and Saccharum spontaneum* (field survey, 2020). Particularly, the rapid and difficult-to-control growth of the *Cyperus cephalotes* Vahl species is narrowing the water surface area and affecting the habitat of various species.

Figure 7. Some plant asociasions in Bau Sau

The surved results also indicated that *Salvinia cucullata, Utricularia aurea* and *Ludwigia adscendens* species are "substrates", while *Cyperus cephalotes* specie is “intermediate" plant association for the formation of different plant associations in the Bau Sau. In hence, some measures have been implemented to control this plant species by the Cat Tien National Park. However, these measures have not been effective. Due to the continuous growth of *Cyperus cephalotes*, after a year, they can grow back to an average height of 20 - 30cm, forming floating vegetation patches that shrink the water surface area of the marsh. This is a significant challenge for the conservation of the wetland area by the managers.

According to the research results, to effectively control the growth of *Cyperus cephalotes* specie, it is necessary to integrate multiple measures at different times. There are some thethods can be use such as control natural succession, control photosynthesis process, control by fire and control by mechanical means.

4. CONCLUSIONS

Landsat 8 and 9 satellite images are used to extract surface water boundary at Bau Sau, Cat Tien National Park. By using egconition and ArcGIS software, the extraction is carried out in three ways including object-based classification, calculation of NDWI and MNDWI indices. The initial calculation for 2024, combined with field survey data and some documents provided by Cat Tien National Park, shows that extracting surface water using the NDWI index is quite suitable for the research area covered by various vegetation’s types with an overall accuracy of 90%. It can be seen that if the study area has dense vegetation cover, NDWI may be more suitable due to its reduced sensitivity to vegetation.

The analysis of surface water changes at Bau Sau showed a decreasing trend in the study area during the period 2015 – 2020 (decreasing by 0.64 ha). The surface water area in 2015, 2020, and 2024 is 42.15 ha, 41.89 ha, and 41.51 ha respectively. The survey results also indicated the presence of 13 plant association types in the wetland areas at Bau Sau. The encroachment of these vegetation types is the main cause of the decrease in surface water area in the research area. Among them, the growth and development of *Cyperus cephalotes* specie are the most notable and require timely management measures.

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