(RESEARCH ARTICLE)

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A comprehensive analysis of surface water changes in Dau Tieng Lake, Vietnam, across dry and wet seasons

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Abstract

This study investigates the seasonal dynamics of Dau Tieng Lake near Tay Ninh, Vietnam, employing remote sensing technology, specifically the Modified Normalized Difference Water Index (MNDWI) and Normalized Difference Vegetation Index (NDVI). Focused on the period from 2016 to 2020, the research aims to detect changes in the water surface area during dry and wet seasons. As the largest reservoir for water supply and irrigation in Vietnam, Dau Tieng Lake faces operational challenges due to seasonal rainfall variations and increasing water demands. The results reveal significant differences in water body areas between wet and dry seasons, with MNDWI proving more effective in capturing these variations compared to NDVI. The study concludes that the seasonal change in Dau Tieng Lake is 21.76 km2 (NDVI) and 25.55 km2 (MNDWI), emphasizing the latter's superiority in accurately detecting water body changes. These findings contribute valuable insights for improved reservoir management and sustainable utilization of water resources in the region.

Keywords: Remote Sensing; Seasonal Dynamics; MNDWI; NDVI; Water Surface Change

1. Introduction

The complex relationship between water and land is the foundation of many societies, influencing their physical environment and social and economic growth [1]. This reliance on essential natural resources is noticeable in countries like Bangladesh and Vietnam, where rivers and reservoirs are crucial in maintaining life and supporting livelihoods. Rivers like the Buriganga in Bangladesh face severe pollution [2]. Some research also reveals the various challenges that are interlinked and threaten the river's health. Additionally, climate change exacerbates the situation by impacting water quality and agricultural productivity in the region [3,4,5]. Further downstream, other research raises concerns about the potential risks posed by utilizing recycled wastewater for irrigation, highlighting the downstream consequences of upstream decisions [6,7]. Such as Kabir et al. (2022) add to this by underscoring the severe health risks associated with heavy metals found in Buriganga and surrounding rice fields, emphasizing the urgency of environmental remediation [6].

The challenges faced by the Buriganga are not unique. In Vietnam, Dau Tieng Reservoir serves as a crucial linchpin in the nation's water supply and irrigation network, catering to the agricultural needs of vast areas and channeling water for domestic consumption in Ho Chi Minh City. However, as the opening passage outlines, the Dau Tieng Reservoir grapples with its operational complexities. Seasonal rainfall fluctuations, surging water demands, and water quality degradation pose significant challenges to managing and operating the reservoir effectively. Bangladesh and Vietnam increasingly turn to technological solutions in response to these intricate challenges. In Bangladesh, research explores the effectiveness of project management tools in mitigating environmental impacts associated with significant

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infrastructure projects. In contrast, another study emphasizes the importance of effective water management practices and flood control infrastructure [8,9,10].

Similarly, in Vietnam, the study on Dau Tieng Reservoir highlights the potential of remote sensing technology in monitoring and understanding the reservoir's dynamics. By employing advanced techniques like the Modified Normalized Difference Water Index (MNDWI), researchers can gain valuable insights into the seasonal changes in the reservoir's water surface, enabling informed decision-making for its management. Vietnam's way of life heavily depends on the relationship between water and land, and the Dau Tieng (DT) Reservoir plays a crucial role in the country's water supply and irrigation system [11]. The reservoir caters to the agricultural needs of around 90,000 hectares in Tay Ninh Province, Long An Province, and Ho Chi Minh City (HCMC) and provides $10m^3$/s of water for domestic use. However, the DT Reservoir faces various operational challenges due to fluctuations in rainfall, increasing water demand, and deteriorating water quality caused by natural and human factors. The complexity of managing and operating the reservoir to meet these diverse needs has led to integrating remote sensing technology as a crucial tool for monitoring and identifying changes in surface water.

The Normalized Difference Water Index (NDWI) has been instrumental in identifying water bodies in Landsat imagery. However, it has limitations, such as false positives from built-up areas. To overcome this, the Modified NDWI (MNDWI) has been introduced. MNDWI uses the near-infrared (NIR) band instead of the middle infrared (MIR) band. This substitution helps to identify surface water accurately and reduces errors from built-up land, vegetation, and soil [12]. Multi-date satellite images are used to detect changes in surface water over time. This allows for meaningful comparisons to be made. This study focuses on Dau Tieng Lake and uses advanced remote sensing techniques to understand the seasonal dynamics of the lake. The insights gained from this study will contribute significantly to managing this essential water resource.

The primary objective of this research is to meticulously detect and analyze changes in the water surface area of Dau Tieng (DT) Lake throughout the dry and wet seasons over the period spanning 2016 to 2020. This endeavor aims to unravel the nuanced dynamics of the lake's water surface, providing a comprehensive understanding of its fluctuations in response to seasonal variations. Furthermore, the study seeks to illuminate the correlation between these observed changes in water surface area and the corresponding shifts in land use patterns, offering valuable insights into the lake's role in seasonal variability. By achieving these objectives, the research aspires to contribute vital knowledge for informed water resource management and sustainable land use practices in the Dau Tieng Lake region.

1.1. Study area

Dau Tieng Lake is one of the largest shallow lakes in Tay Ninh Province, South Vietnam. It has a V-shaped structure that rises towards the north, with coordinates of 11° 23' 58" N latitude and 106° 20' 33" E longitude. The lake is located 25 km east-west of Tay Ninh town and 70 km north of Hochiminh city. It is the most extensive irrigation system in Vietnam, covering an area of 270 km2, with a water area of 27000 ha and about 1.45-1.5 billion m3 of water used to irrigate 175,000 ha of agricultural land [13]. The lake is affected by a tropical monsoon climate, with a rainy season from May to November and a dry season from December to April. The average annual rainfall is 1850 mm, with 80% falling in the rainy season.

The storage capacity of the Dau Tieng reservoir ranges from 470 to 1.68 billion m^3, depending on the water level. At the dead water level of 17 m, the reservoir has a storage capacity of 470 million m^3, while at the average operation water level of 24.4 m, the storage capacity is 1.68 billion m^3. The surface water area of the lake is 120 km2 at a water level of 17 m and 270 km2 at a water level of 24.4 m. The average and maximum water depths are 6.2 m and 25.1 m, respectively. This makes the Dau Tieng Reservoir the fourth largest reservoir in Vietnam [14]. The average precipitation, rainfall amount in different years, average temperature, and crop calendar vary in the DT Lake near the station (Figures 2, 3, 4 & 5).
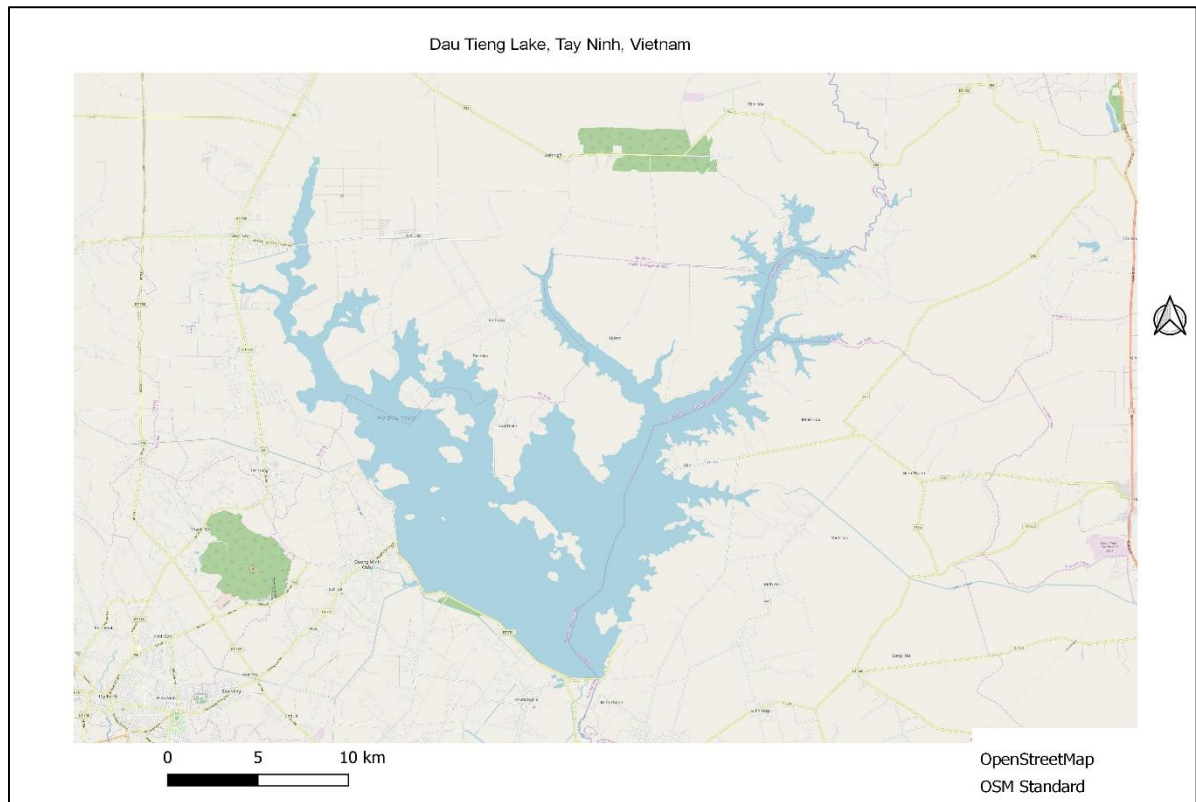
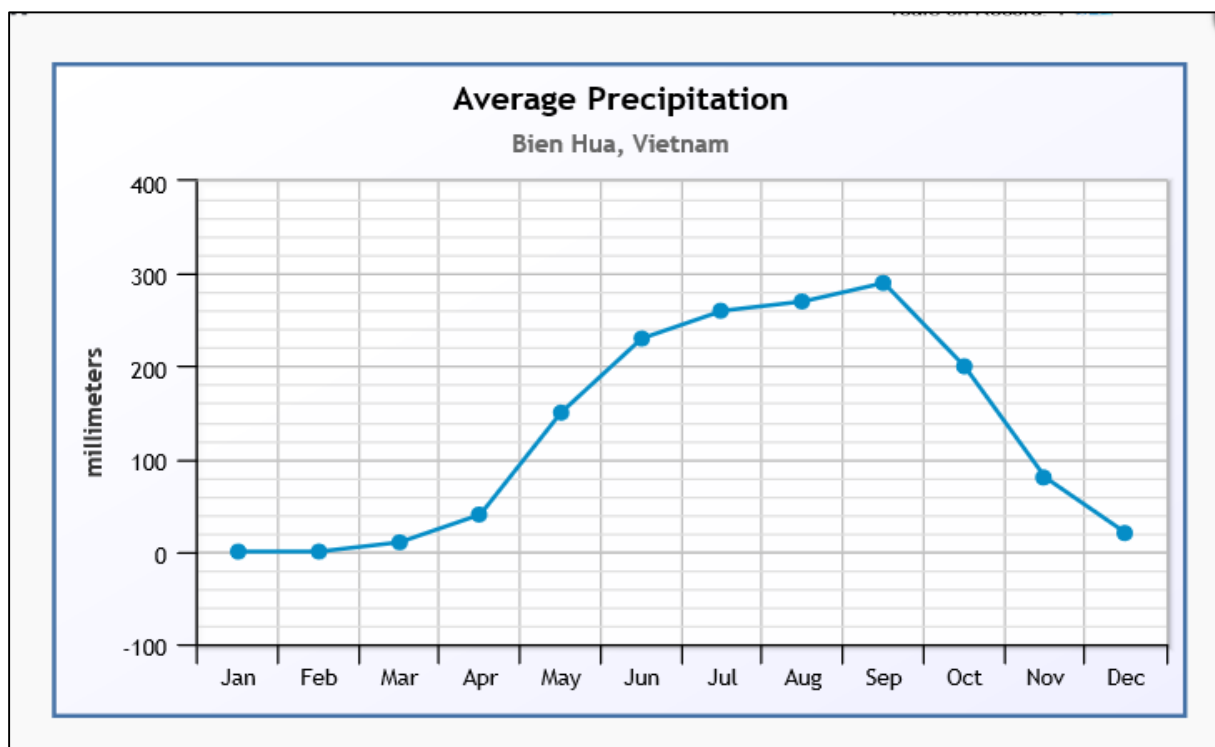**Figure 1** The Dau Tieng Lake near Tay Ninh Province, Vietnam (Study Area)

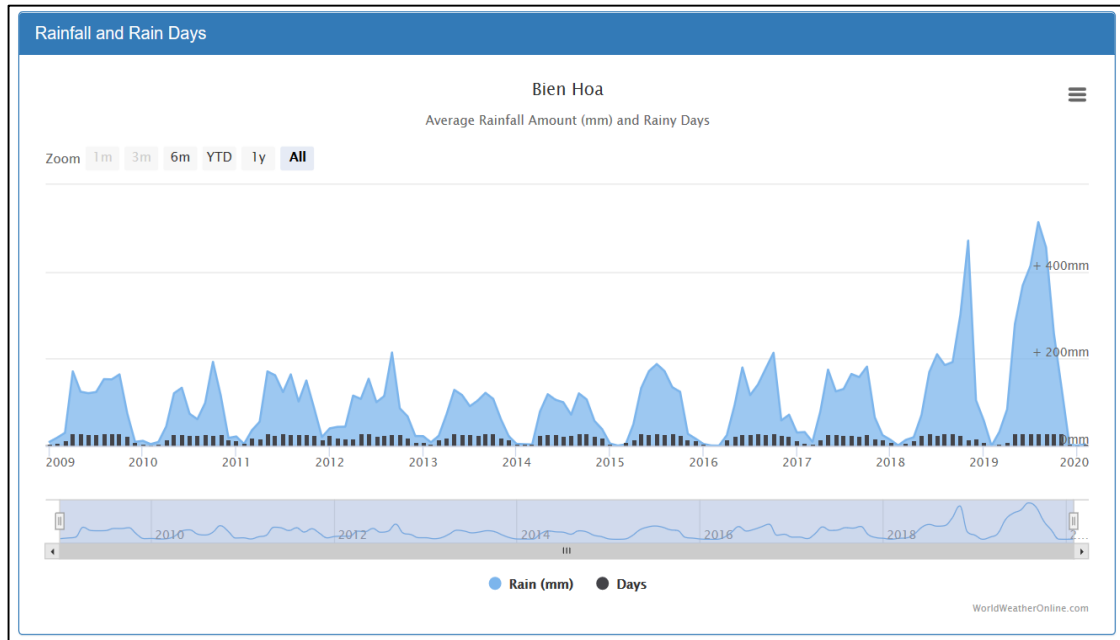**Figure 2** The average precipitation near the station of the Dau Tieng Lake [14]

Figure 3 The average rainfall amount near the station of the Dau Tieng Lake [14]
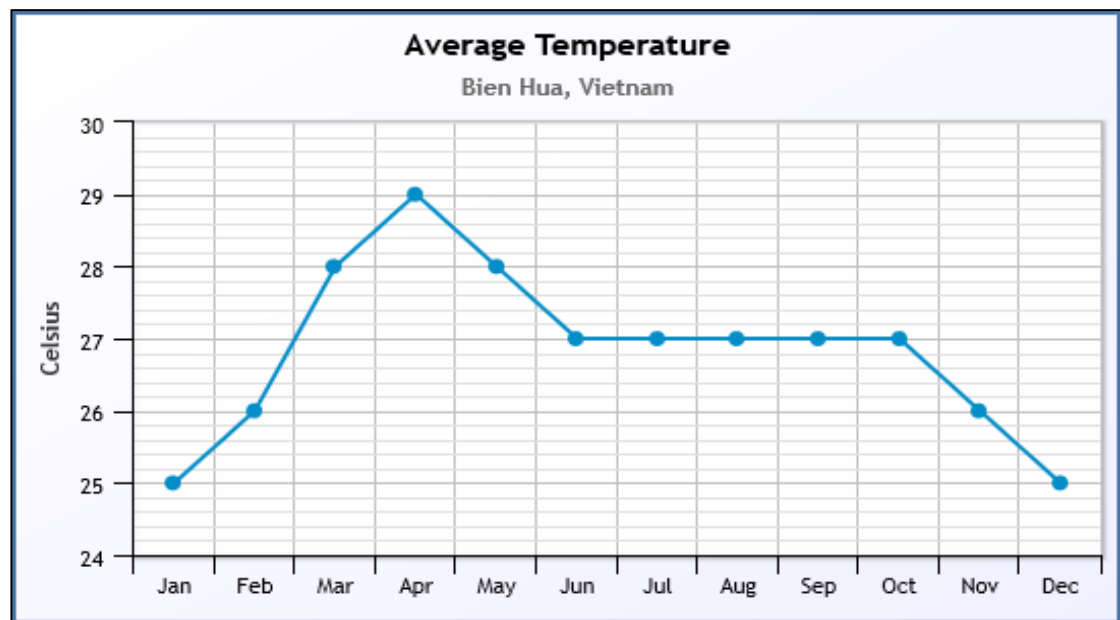

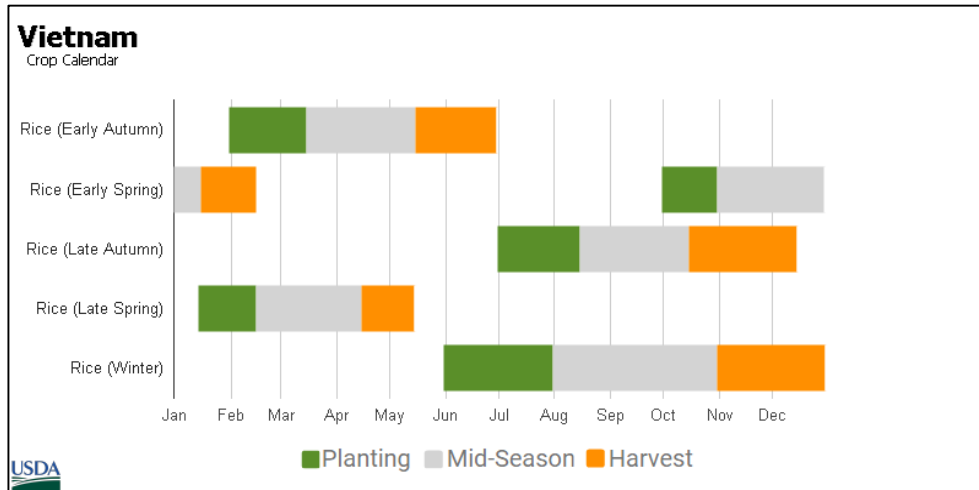**Figure 4** The average temperature variation in the near station of the study area [14]

Figure 3 The seasonal crop calendar in the Vietnam [15]

2. Methodology

To perform the objectives of the study in the Dau Tieng Lake near Tay Ninh province, Vietnam, the dry and wet periods were separated based on a literature study and world weather recording access. Then, the band images of Landsat-8 OLI /TIRS C1 level-2 were downloaded to conduct the steps of changing surface area during the period of 2016 to 2020. The path 125, row 52 with 30 meter resolution was used to download the image. One scene of Landsat-8 OLI /TIRS C1 level-2 data with projection: WGS 84 / UTM zone 48N (EPSG:32648) from October to November in 2018 that is a wet period and another scene of the same satellite data for February that is a dry period were obtained from the US Geological Survey (USGS) Global Visualization Viewer (Table 1). During the image selection, less than 15% cloud cover was considered.

Table 1 The specifications of Landsat-8 OLI data during 2016-2020 (dry and wet season)

Path/ Row	Band	Centre Wave length μm (1 E-6m)
125/ 52	Band 2	0.48
	Band 3	0.56
	Band 4	0.655
	Band 5	0.865
	Band 6	1.61
	Band 7	2.2

Then, a false color composite was generated using the 5-4-3 band as NIR, red, and green, respectively. After that, the Normalized Difference Vegetation Index (NDVI) and Modified Normalized Difference Water Index (MNDWI) both index were calculated using the raster calculator algorithm (Table 2). It is necessary to mention that the NDVI has a negative value, and the MNDWI has a positive value with respective bands that were considered to generate the band ratios for the dry season and wet season map.

Table 2 The Equation and Bands of NDI calculation using QGIS

Index	Equation	Remarks	Respective Band
Modified Normalized Difference Water Index	MNDWI = (Green − NIR)/(Green + NIR)	Water has positive value [16]	Green: Band 3 and NIR: Band 6
Normalized Difference Vegetation Index	NDVI = (NIR − Red)/(NIR + Red)	Water has negative value [17]	NIR: Band 5 and Red: Band 4

The water profile tool was used to identify threshold values for both the NDVI (dry and wet) and MNDWI (dry and wet) maps. The reclassified values algorithm was then used to obtain binary maps based on these threshold values, which will help detect water bodies. Water values depend on whether it is the wet or dry season, as shown in Table 3. The differences between the wet and dry seasons were calculated using the raster calculator algorithm for both the NDVI and MNDWI. Finally, to obtain the map of the Dau Tieng Lake (study area), the binary maps were clipped, and the area in square kilometers was obtained using the raster unique values algorithm. This process was performed for both the NDVI (dry and wet) and MNDWI (dry and wet) indices.

Table 3 The values of water to detect the water bodies

Dry ＼ Wet	1	0
1	0	-1
0	1	0

3. Results and discussion

In comparison, in the false color composite (FCC) of the dry and wet seasons, the more red color indicates more vegetation during the wet season (Figures 6 & 7).
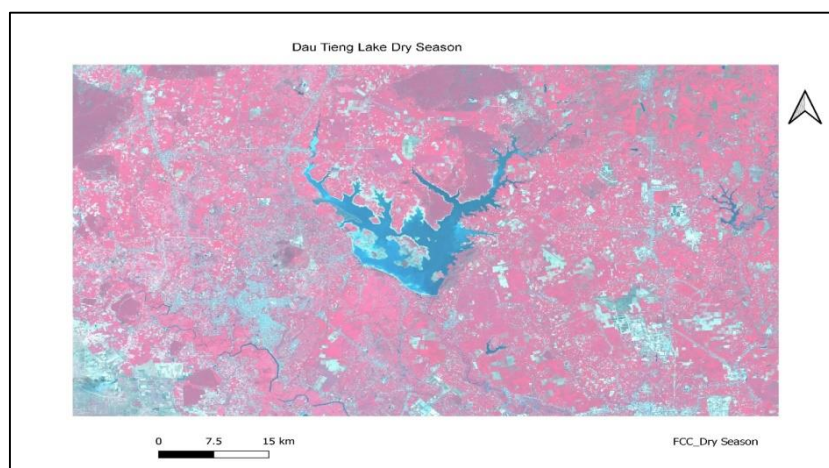

Figure 4 The false colour composite during dry season in the Dau Tieng Lake area
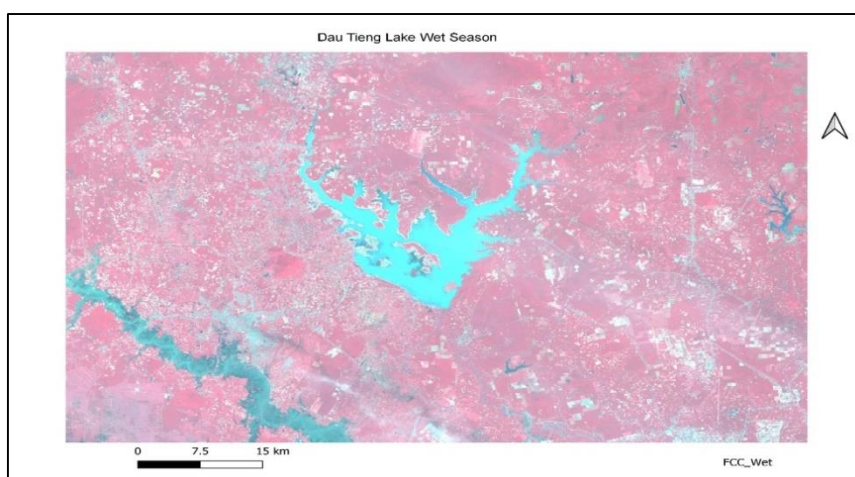

Figure 5 The false colour composite during wet season in the Dau Tieng Lake area

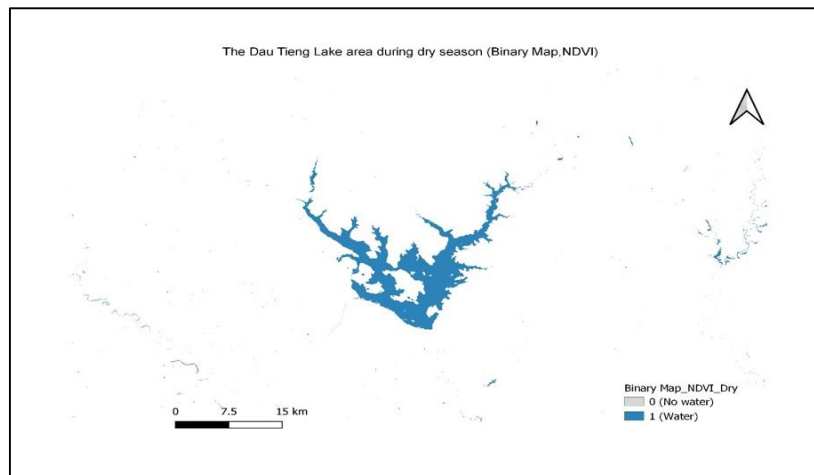The NDVI results during dry and wet season in the period of 2016 to 2020:

Figure 6 The generation of the binary map for the dry season in the DT Lake area
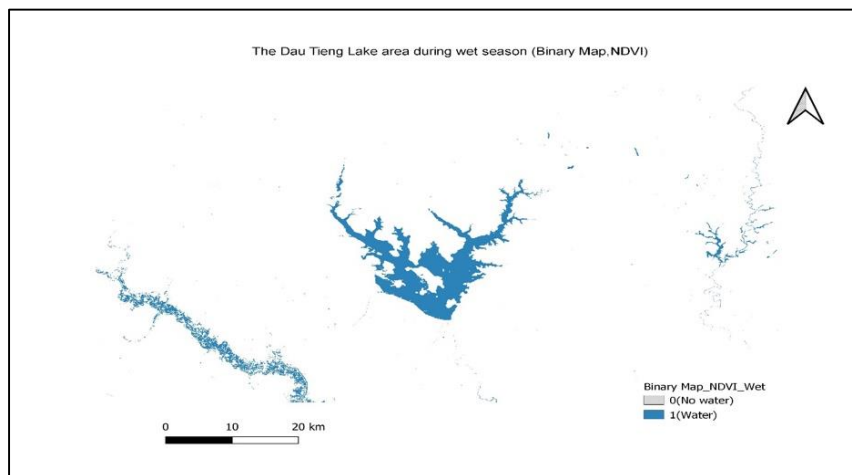

Figure 7 The generation of the binary map for the wet season in the DT Lake area

The visual inspection between the wet season and dry season binary map is the wet season occupying the more water in the water bodies that is reasonable (Figure 8 & 9). Since, most of the rainfall occur during wet season in the study area. The obtained threshold values for the NDVI dry and wet is -0.057 and -0.026 respectively (Table 4).

The percentage of water body area is higher in the wet season than dry season which is the result of heavy rainfall during wet season. The amount of rainfall filled up the water body during wet season.

Table 4 The obtained threshold values from the binary maps

The Index with season	The threshold values
NDVI (dry)	-0.057
NDVI (wet)	-0.026
MNDWI (dry)	0.086
MNDWI (wet)	0.097

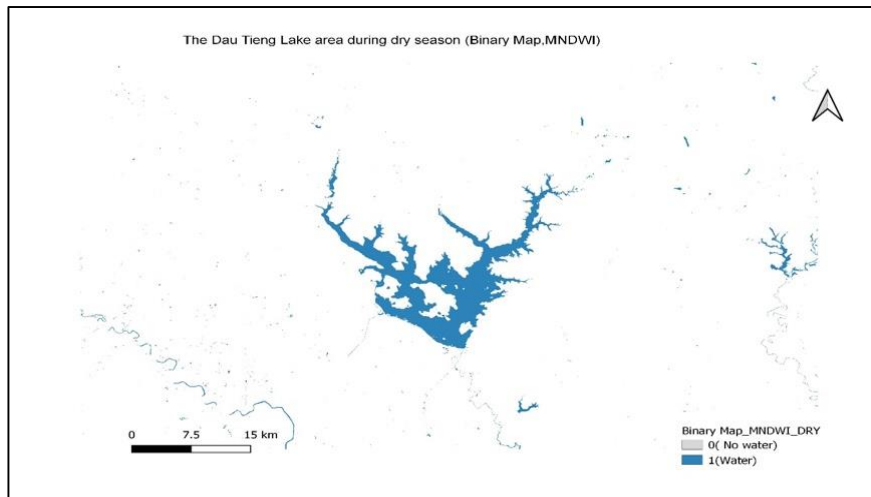The MNDWI results during dry and wet season in the period of 2016 to 2020:

Figure 8 The generation of binary map for MNDWI during dry season in the DT Lake area
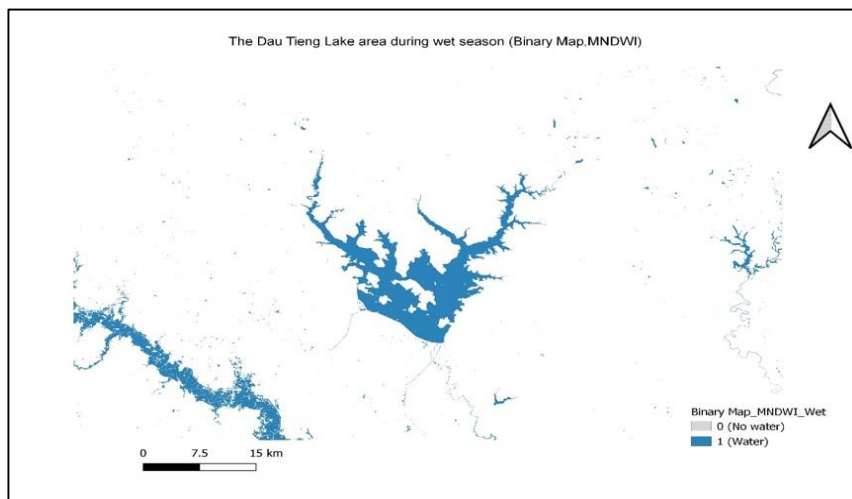

Figure 9 The generation of binary map for MNDWI during wet season in the DT Lake area

It was found that the MNDWI calculation yielded the same results during both the dry and wet seasons. This implies that the wet season receives more rainfall than the dry season (as seen in figures 10 and 11). However, there were differences between the results obtained using the NDVI and MNDWI indices. The MNDWI index was able to capture the water body area more accurately than the NDVI index, which calculates both vegetation coverage and water body. In contrast, the MNDWI index focuses solely on the water body area, resulting in better outcomes when analyzing the seasonal changes in water bodies.

The Difference from Wet to Dry indicate the response of land use during dry and wet season. The Red areas (-1) indicates there were no water during wet season. The availability of water during both dry and wet season is identified by the white areas (0). In blue areas (1) indicate, there were no water during dry season. (Figure 12 & 13).
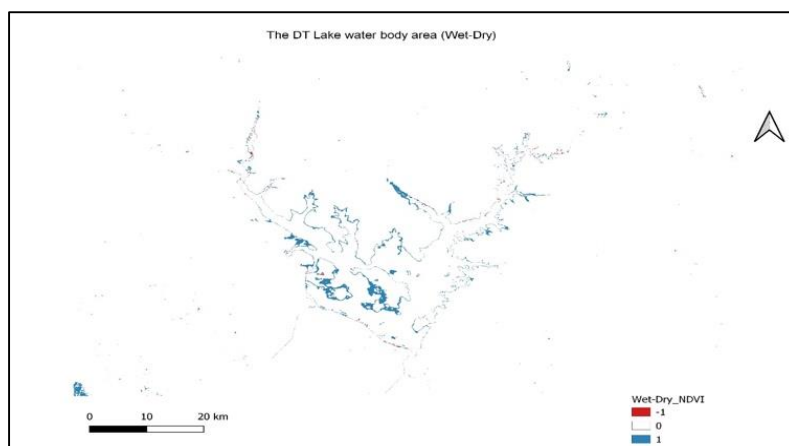
Figure 10 The Difference from Wet to Dry season for NDVI calculation in the water bodies
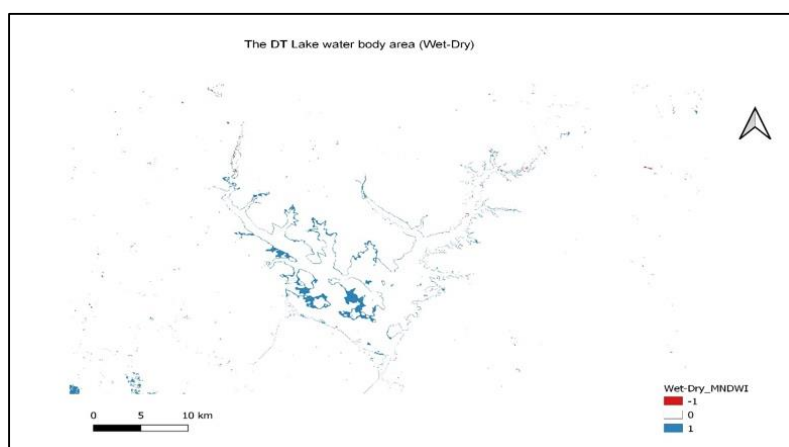

Figure 11 The Difference from Wet to Dry for MNDWI calculation in the water bodies

The region surrounding the lake experiences seasonal changes. During the dry season, some areas do not receive enough water to support crop growth and vegetation, necessitating the use of irrigation to make up for the deficit. However, there is ample water available to cultivate paddy during the wet season. Literature suggests that Vietnam produces more rice during the wet season compared to the dry season, which is consistent with the findings obtained through remote sensing.
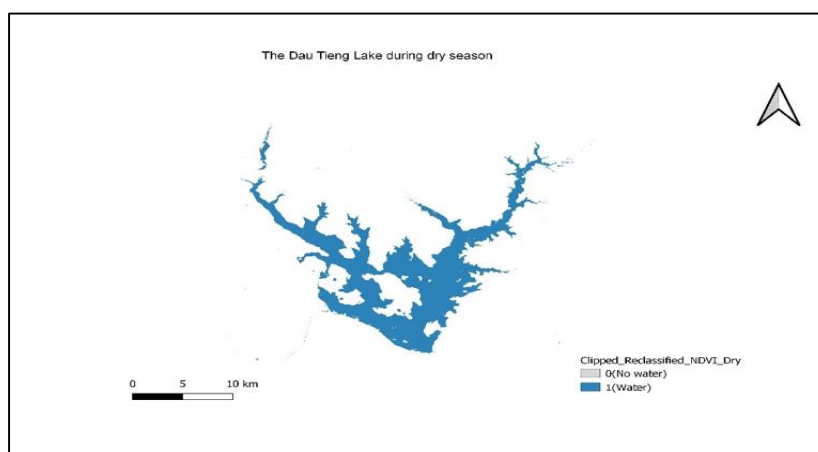

Figure 12 The Dau Tieng Lake based on NDVI_DRY index

According to Table 5, the water area of Dau Tieng Lake is 162.243 km2 during the dry season and 184.0077 km2 during the wet season when measured using the NDVI index. When using the MNDWI index, the water area is 173.3247 km2 during the dry season and 198.873 km2 during the wet season. The lake experiences seasonal changes in its water area, with more water present during the wet season compared to the dry season. This is illustrated in Figures 14 to 17.
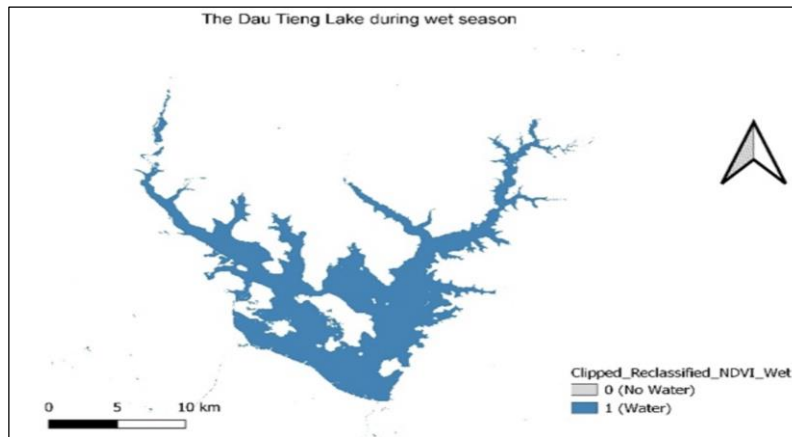

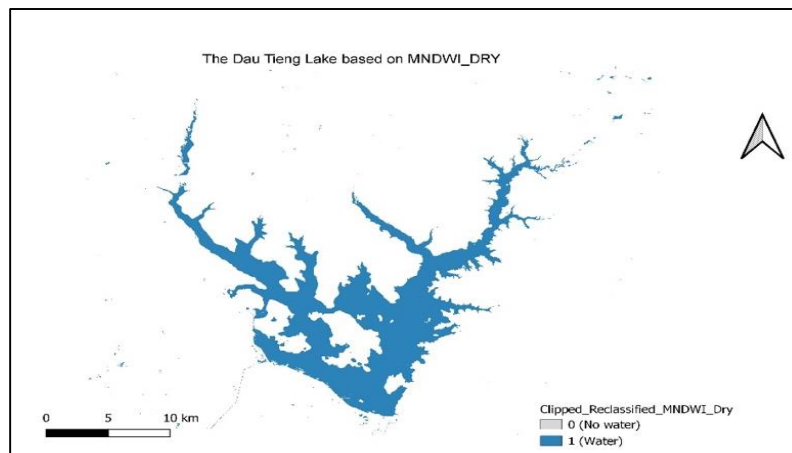**Figure 13** The Dau Tieng Lake based on NDVI_WET index

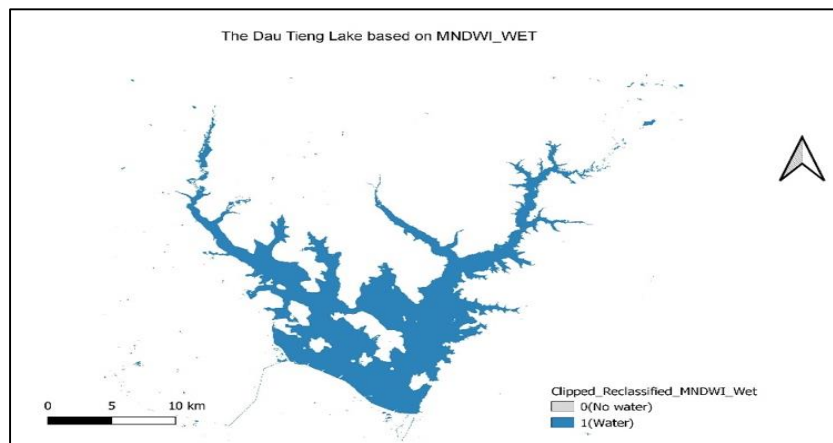**Figure 14** The Dau Tieng Lake based on MNDWI_DRY index

Figure 15 The Dau Tieng Lake based on MNDWI_WET index

Table 5 The seasonal change of Surface water area for the Dau Tieng Lake near Tay Ninh, Vietnam

The Index with season	The water body area (the Dau Tieng Lake) km²
NDVI (dry)	162.243
NDVI (wet)	184.0077
MNDWI (dry)	173.3247
MNDWI (wet)	198.873

4. Conclusion

Dau Tieng Lake stands as a crucial water source in Tay Ninh Province, contributing significantly to Vietnam's water landscape. The study, focused on assessing the seasonal dynamics of the lake, reveals a substantial seasonal change in water surface area. Specifically, the NDVI index indicates a change of 21.7647 km², while the MNDWI index demonstrates a more pronounced alteration of 25.5483 km². Notably, the MNDWI emerges as the more accurate indicator compared to the NDVI index, showcasing its efficacy in precisely capturing variations in water body extents. These findings underscore the importance of advanced remote sensing techniques, particularly the MNDWI index, in providing nuanced insights into the evolving dynamics of Dau Tieng Lake. As water resources play a pivotal role in the region's sustainability, the knowledge derived from this study holds significant implications for informed decision-making in water resource management and underscores the need for continued monitoring of this vital ecosystem.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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