International Journal of Scientific Engineering and Science
Volume 10, Issue 7, pp. 1-7, July 2026.
ISSN (Online): 2456-7361

Sentinel 2 Reveals a Weakening Wet Season Recovery of Dau Tieng Reservoir Surface Water

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Abstract**—***Reservoir surface water extent is a practical indicator of seasonal storage response where continuous gauge and release data are limited. This study quantified recent dry and wet season changes in Dau Tieng Reservoir, southern Vietnam, using Sentinel 2 multispectral imagery and the Normalized Difference Water Index. Cloud minimized scenes representing March and October of 2023 and 2025 were clipped to the reservoir boundary, transformed to NDWI from the green and near infrared bands, classified with a zero threshold, cleaned by majority filtering, and converted to polygons for area and change analysis. The dry season surface water area declined from 18,482.58 ha in 2023 to 17,821.98 ha in 2025, a net reduction of 660.60 ha or 3.57 percent. The wet season decline was substantially larger, from 21,047.67 ha to 19,286.28 ha, equivalent to 1,761.39 ha or 8.37 percent. Consequently, the seasonal wet to dry expansion decreased from 2,565.09 ha to 1,464.30 ha, indicating a 42.91 percent contraction in seasonal recovery. Losses were concentrated along shallow northwestern margins and tributary arms, whereas the deeper southern core remained comparatively stable. A spatial consistency check against the long term JRC recurrent water envelope produced area agreement values of 93.75 to 95.66 percent for the 2023 masks. The findings demonstrate that a simple and automatable Sentinel 2 NDWI workflow can provide an operational early warning of incomplete wet season replenishment, while causal interpretation still requires rainfall, inflow, release, and water level records.*

Keywords**—** *Change detection, Dau Tieng Reservoir, NDWI, Reservoir monitoring, Sentinel 2, Surface water.*

I. INTRODUCTION

Large reservoirs are central to irrigation, domestic and industrial water supply, flood control, salinity regulation, and ecological maintenance. Their exposed surface area changes rapidly in response to inflow, withdrawals, evaporation, operating rules, and basin morphology. Conventional gauges provide accurate point measurements, but they do not directly describe the spatial redistribution of water across shallow shelves, tributary arms, and semi inundated margins. Satellite remote sensing therefore offers an important complement by providing repeatable synoptic observations at relatively low cost.

The Sentinel 2 mission was designed for frequent high resolution land monitoring and provides green and near infrared bands at 10 m spatial resolution [1]. For open water delineation, McFeeters introduced the Normalized Difference Water Index, or NDWI, to exploit the relatively high green reflectance and strong near infrared absorption of water [2]. Xu later proposed the Modified NDWI to suppress built up and soil noise by substituting a shortwave infrared band [3], while Feyisa, Meilby, Fensholt, and Proud developed the Automated Water Extraction Index for landscapes affected by shadows and dark surfaces [4]. Subsequent Sentinel 2 studies have shown that index selection, spatial resolution, atmospheric effects, and thresholding strategy influence shoreline detection, particularly near mixed pixels and turbid or vegetated margins [5], [6], [16].

At broader scales, long term surface water products have revealed extensive global gains and losses and demonstrated the value of consistent satellite archives for environmental management [7], [8]. More recent approaches combine Sentinel 2 and Landsat time series [9] or integrate optical and radar observations to reduce cloud related data gaps [10]. These developments support a shift from occasional mapping toward repeatable reservoir monitoring workflows that can be incorporated into operational decision systems.

Vietnamese studies have increasingly applied satellite data to reservoir environments. At Dau Tieng Reservoir, Naher, Nabir, and Kadir analyzed dry and wet season surface water changes during 2016 to 2020 using MNDWI and NDVI [11], while Van and coauthors combined remotely sensed imagery with monitoring data to assess water quality patterns [12]. Elsewhere in Vietnam, Sentinel 2 has been used to identify drought related reservoir contraction in Dak Lak [13], to estimate storage dynamics in Tuyen Quang Reservoir [14], and to map suspended sediments in Hoa Binh Reservoir [15]. Together, these studies confirm the suitability of Earth observation for reservoir assessment, but they also show that operational interpretation is strongest when water extent is linked to water level, bathymetry, inflow, rainfall, and release records.

Despite the strategic importance of Dau Tieng Reservoir, recent same season comparisons after 2023 remain limited, and the spatial balance between stable water, loss, and gain has not been documented in a compact automated workflow. This study addresses that gap by comparing representative dry and wet season Sentinel 2 observations from 2023 and 2025. The contributions are fourfold: first, it provides updated seasonal surface water estimates at 10 m resolution; second, it separates stable water, water loss, and water gain spatially; third, it quantifies the weakening of wet season recovery rather than reporting only annual area differences; and fourth, it formalizes an ArcGIS based workflow that can be rerun as new imagery becomes available.

II. Materials and Methods

A. Study Area

Dau Tieng Reservoir is located in the upper Sai Gon River basin and extends across Tay Ninh, Binh Duong, and Binh Phuoc provinces in southern Vietnam. The main reservoir lies approximately between 11 degrees 14 minutes and 11 degrees 29 minutes north latitude and 106 degrees 17 minutes and 106 degrees 25 minutes east longitude. It is a large multipurpose irrigation reservoir with a reported storage capacity of about 1.58 billion cubic meters and an average water surface of roughly 27,000 ha, supporting irrigation, water supply, downstream flow regulation, flood attenuation, and salinity control [11], [12].

The basin morphology is important for interpreting planimetric change. The northern and northwestern arms are shallow and gently sloping, so a small change in water level can expose a broad semi inundated surface. The southern sector near the main dam and outlet structures is deeper and retains a more stable water footprint. Accordingly, shoreline migration is expected to be spatially uneven even when the reservoir experiences a single water level change.

B. Satellite Data and Preprocessing

The analysis used Sentinel 2 Multispectral Instrument Level 1C imagery representing the peak dry season in March and the wet season storage period in October for 2023 and 2025. Scenes were identified in Google Earth Engine and selected to minimize cloud contamination over the reservoir, with scene cloud cover below 5 percent. The green band B3 and near infrared band B8 were used at their native 10 m resolution. Administrative and reservoir boundary vectors were used to limit the analysis to the study area.

Processing was completed in ArcGIS Desktop 10.8. The input bands were stacked where required, clipped to the reservoir analysis boundary, checked visually for cloud and shadow contamination, and projected to VN 2000 UTM Zone 48N before area calculation. Using a projected coordinate system ensured that polygon areas were measured in square meters and converted consistently to hectares.

TABLE I. Satellite Data and Processing Specifications

Seasonal observation	Representative period	Sentinel product	Bands and resolution	Selection and use
Dry 2023	March 2023	Sentinel 2 MSI Level 1C	B3 Green and B8 NIR, 10 m	Cloud minimized scene; baseline dry extent
Wet 2023	October 2023	Sentinel 2 MSI Level 1C	B3 Green and B8 NIR, 10 m	Cloud minimized scene; baseline wet extent
Dry 2025	March 2025	Sentinel 2 MSI Level 1C	B3 Green and B8 NIR, 10 m	Cloud minimized scene; recent dry extent
Wet 2025	October 2025	Sentinel 2 MSI Level 1C	B3 Green and B8 NIR, 10 m	Cloud minimized scene; recent wet extent

C. NDWI Water Extraction

NDWI was calculated using the green and near infrared bands because open water generally reflects more strongly in the green wavelengths and absorbs near infrared energy. For each observation, the index was calculated as follows:

$$NDWI = (B3 - B8) / (B3 + B8). \qquad (1)$$

The resulting index ranges theoretically from minus one to one. Pixels with NDWI greater than zero were classified as open water, while values equal to or below zero were classified as nonwater. A fixed zero threshold was retained for consistency among the four observations and because visual inspection showed a clear separation of the main reservoir from surrounding land. This decision favors reproducibility, although it may underestimate water beneath floating vegetation and may be sensitive to turbid shallow margins.

The binary masks were cleaned using a majority filter and boundary cleaning to remove isolated pixels and small classification artifacts. Masks were converted from raster to polygon, clipped again to the reservoir boundary, and assigned area fields in hectares. At 10 m resolution, each complete pixel represents 100 square meters, or 0.01 ha, before vector boundary effects.

D. Change Detection and Seasonal Recovery

Same season change was assessed by overlaying the 2023 and 2025 water polygons. The intersection represented stable water. Water loss was calculated as the 2023 water polygon minus the 2025 polygon, and water gain was calculated as the 2025 polygon minus the 2023 polygon. The net change was defined as water gain minus water loss, which is equivalent to the difference between the total 2025 and 2023 surface water areas.

In addition to same season differences, the study calculated the seasonal recovery amplitude within each year as the wet season area minus the dry season area. Comparing this amplitude between 2023 and 2025 provides a direct indicator of how much of the reservoir margin was re inundated after the dry season. A reduction in this amplitude is interpreted as weaker wet season surface recovery, not as a direct estimate of storage volume.

E. Consistency Assessment and Workflow

The 2023 water masks were compared with the high occurrence and recurrent water envelope from the Joint Research Centre Global Surface Water data set [7]. Because the JRC version used covers 1984 to 2021, it was treated as a long term spatial plausibility layer rather than date matched ground truth. The reported ratios therefore indicate area consistency with the historical water envelope and must not be interpreted as classification accuracy from independent field samples.

The processing sequence was organized in ArcGIS ModelBuilder so that the input image and output path can be changed without repeating the intermediate operations manually. The workflow includes data selection, preprocessing, NDWI calculation, thresholding, postprocessing, polygon area calculation, seasonal overlay, and reference comparison, as summarized in Fig. 1.

Volume 10, Issue 7, pp. 1-7, July 2026.
ISSN (Online): 2456-7361

III. RESULTS

A. Seasonal Surface Water Extent

The extracted surface water areas show a consistent reduction from 2023 to 2025 in both seasons. During the dry season, the mapped area decreased from 18,482.58 ha to 17,821.98 ha. During the wet season, the area decreased from 21,047.67 ha to 19,286.28 ha. The wet season reduction was 2.67 times the dry season reduction in absolute area, indicating that the most important change was not simply lower dry season water but incomplete re expansion during the subsequent wet season.

The seasonal expansion from dry to wet conditions reached 2,565.09 ha in 2023 but only 1,464.30 ha in 2025. Thus, the area newly inundated between March and October was 1,100.79 ha smaller in 2025, a 42.91 percent reduction in seasonal expansion. The maps in Fig. 3 show that the deeper southern basin remained broadly connected in all observations, whereas the northern branches and shallow western margins changed markedly.

B. Spatial Patterns of Water Loss and Gain

Overlay analysis separated the total change into stable, lost, and gained water. In the dry season comparison, 17,519.49 ha remained water in both years, 963.09 ha changed from water to nonwater, and 302.49 ha changed from nonwater to water. In the wet season comparison, 18,978.48 ha remained stable, 2,069.19 ha was lost, and 307.80 ha was gained. The similarity of the gain component between seasons contrasts with the more than twofold increase in wet season loss, reinforcing the conclusion that the 2025 wet season footprint did not recover to the 2023 extent.

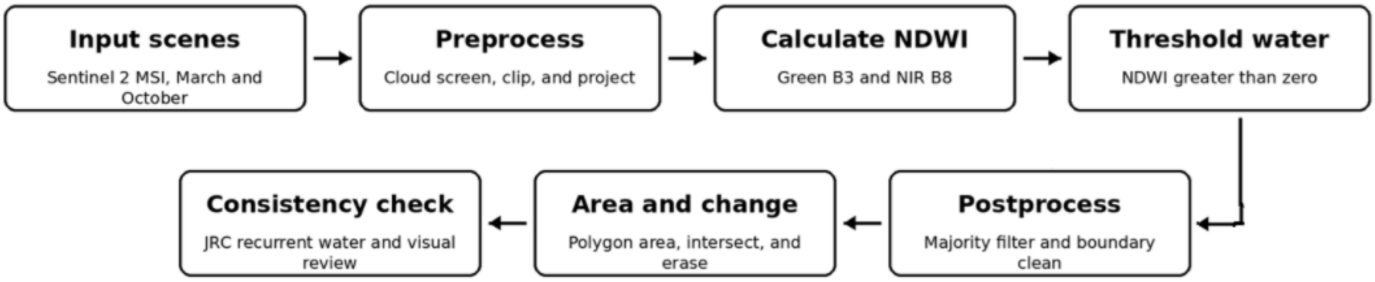

Fig. 1. Workflow for Sentinel 2 NDWI water extraction, area calculation, change detection, and consistency assessment.

TABLE II. Seasonal Surface Water Area and Net Change

Season	Area 2023 (ha)	Area 2025 (ha)	Net change (ha)	Relative change (%)	Interpretation
Dry season	18,482.58	17,821.98	-660.60	-3.57	Moderate contraction
Wet season	21,047.67	19,286.28	-1,761.39	-8.37	Strong contraction
Wet minus dry	2,565.09	1,464.30	-1,100.79	-42.91	Weaker seasonal recovery

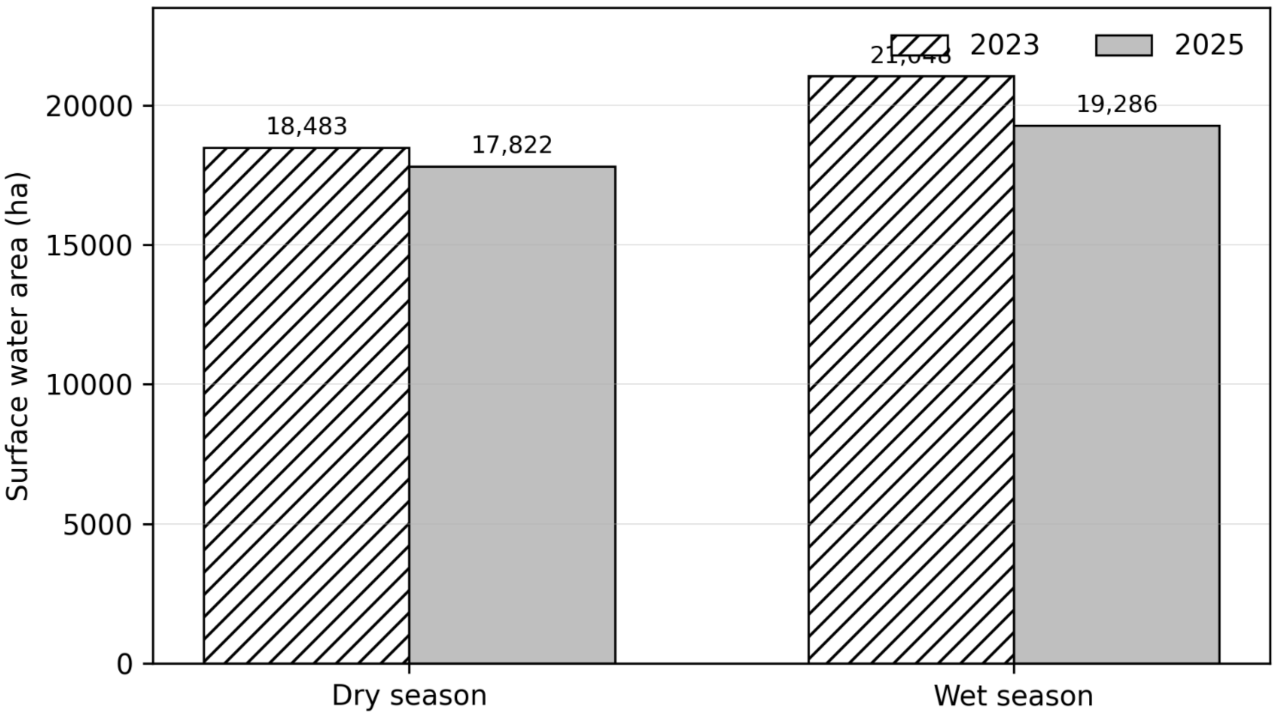

Fig. 2. Dry and wet season surface water areas in 2023 and 2025. Values above the bars are hectares.

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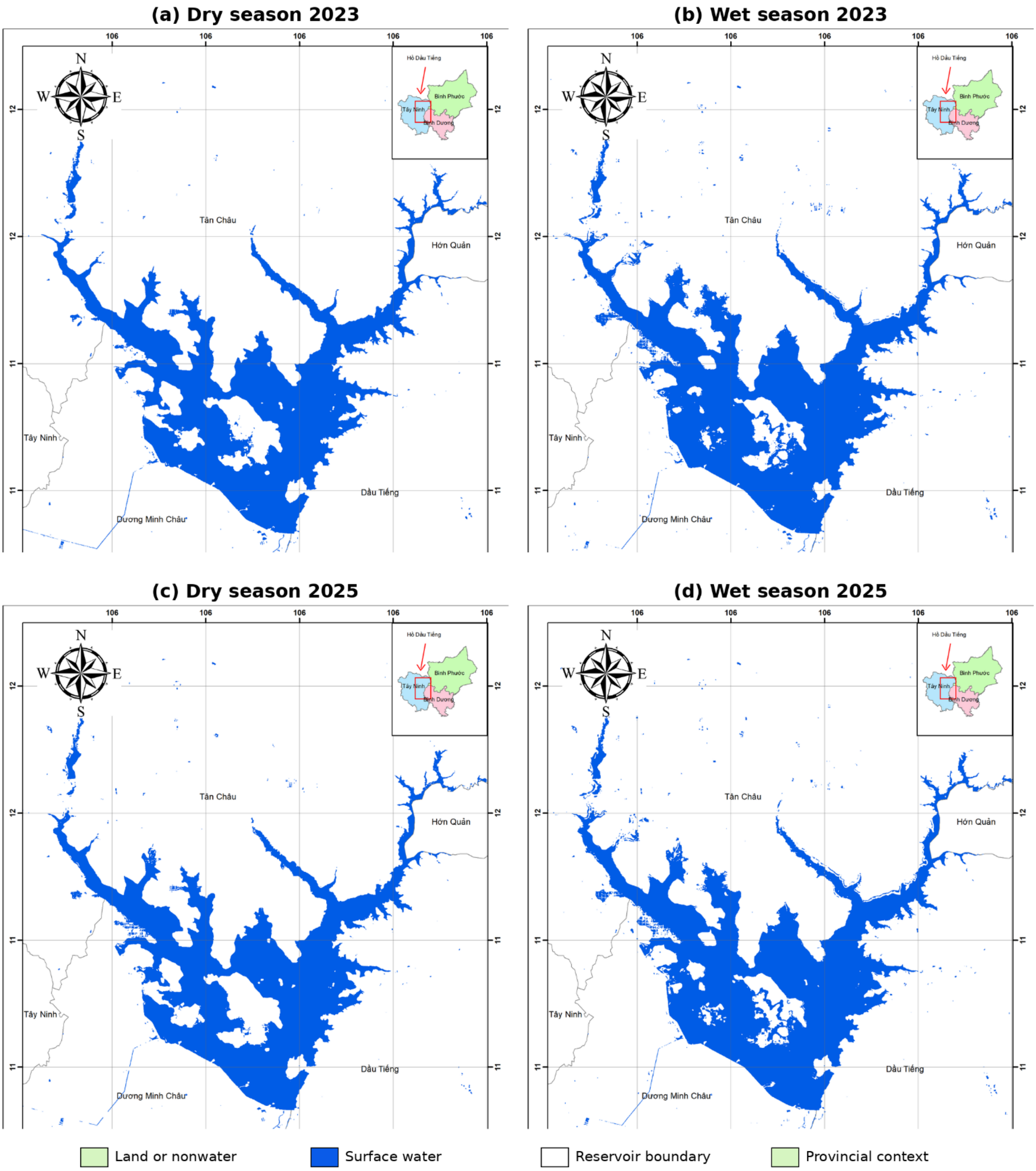

Fig. 3. Extracted reservoir surface water for the dry and wet seasons of 2023 and 2025. The locator inset shows the reservoir position across Tay Ninh, Binh Duong, and Binh Phuoc provinces.

TABLE III. Spatial Components of Same Season Change

Season	Stable water (ha)	Water loss (ha)	Water gain (ha)	Net change (ha)
Dry season	17,519.49	963.09	302.49	-660.60
Wet season	18,978.48	2,069.19	307.80	-1,761.39

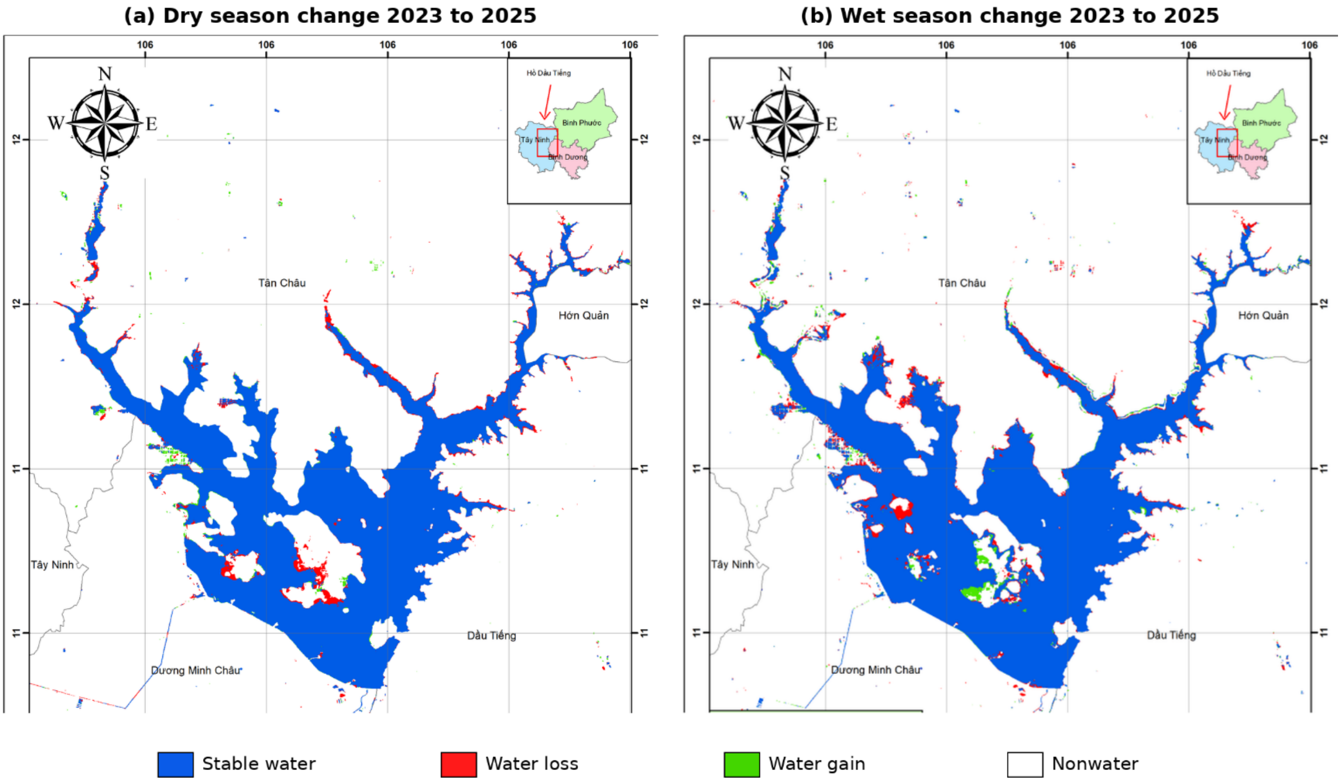

Fig. 4. Stable water, water loss, and water gain between 2023 and 2025 for the dry and wet season comparisons.

Water loss was concentrated along the shallow northwestern and western shoreline, at upstream tributary arms, and around internal shallow margins. In these locations, the shoreline moved inward and formerly connected water became narrow channels, isolated pools, or exposed land. The spatial pattern is consistent with the low gradient morphology described for the northern part of the reservoir. By contrast, the southern core near the dam remained predominantly stable.

Small water gain patches occurred near internal depressions, shallow eastern margins, and the deeper central and southern sectors. These patches may represent local differences in acquisition date, short term reservoir operations, geomorphic redistribution, or classification uncertainty at mixed shoreline pixels. Because the gain area was relatively small and spatially fragmented, it did not offset the coherent margin wide loss observed in either season.

C. Consistency with the JRC Water Envelope

The 2023 NDWI masks were spatially consistent with the historical JRC recurrent water envelope. The dry season mask represented 95.66 percent of its comparison envelope, and the wet season mask represented 93.75 percent. More than 90 percent of the extracted water reportedly overlapped pixels with high historical water occurrence. These values support the spatial plausibility of the mapped reservoir core, but they do not quantify omission and commission errors against contemporaneous field observations.

TABLE IV. Area Consistency Of 2023 NDWI Masks with the JRC Recurrent Water Envelope

Observation	Sentinel 2 NDWI area (ha)	JRC comparison envelope (ha)	Area consistency (%)
Dry season 2023	18,482.58	19,320.00	95.66
Wet season 2023	21,047.67	22,450.00	93.75

IV. Discussion

A. Weakening Wet Season Recovery

The principal finding is the disproportionate reduction in wet season area relative to dry season area. A reservoir may show a small dry season difference because operating rules maintain a minimum pool or because the comparison images were acquired at slightly different points in the release cycle. The 8.37 percent wet season reduction is more consequential because October is expected to represent a period of replenishment and broad inundation of shallow margins. The 42.91 percent decline in wet to dry expansion therefore provides a clearer indicator of weakened seasonal recovery than either seasonal area alone.

The result extends earlier work at Dau Tieng Reservoir that documented seasonal variability during 2016 to 2020 [11]. It also agrees with the broader evidence from Vietnamese reservoirs that high resolution satellite imagery can capture drought related or operationally driven shoreline contraction [13], [14]. However, the present analysis should not attribute the 2025 change to a single cause. Reduced basin rainfall, altered inflow timing, evaporation, irrigation and water supply releases, upstream regulation, and the exact satellite acquisition dates can all influence the mapped surface area. A causal assessment requires the corresponding time series of precipitation, reservoir stage, inflow, evaporation, and releases.

B. Role of Reservoir Morphology

The concentration of losses along northern and northwestern arms is consistent with the geometry of a shallow reservoir. Where the bed slope is low, a modest vertical water level change produces a large horizontal shoreline displacement. This explains why more than 1,700 ha of net wet season water area could be lost while the deeper southern core remained visually stable. The same morphology also means that planimetric area is an especially sensitive early warning indicator, but it is not a direct substitute for storage volume. Converting area change to volume requires an area elevation or area storage relationship derived from bathymetry and water level records, as demonstrated in reservoir studies elsewhere in Vietnam [14].

The spatial location of exposed margins has practical implications. Repeated exposure can alter semi inundated habitats, increase opportunities for temporary cultivation or encroachment, and make fine sediments vulnerable to remobilization when water returns. At the same time, shallow disconnected pools may experience higher temperature, greater aquatic vegetation cover, and poorer water quality. These issues are relevant because previous research has already identified water quality pressures within Dau Tieng Reservoir [12].

C. Method Performance and Uncertainty

NDWI is appropriate for a large open reservoir because it uses native 10 m Sentinel 2 bands and produces an interpretable water response [2]. The fixed zero threshold also makes the workflow transparent and easy to automate. Nevertheless, no single threshold is optimal under all optical conditions. Turbid shallow water, moist exposed sediment, cloud shadow, adjacency effects, and mixed shoreline pixels can shift NDWI values. Floating vegetation may be omitted because its near infrared reflectance resembles terrestrial vegetation. MNDWI and AWEI can reduce some land and shadow confusion [3], [4], and 10 m MNDWI products can preserve spatial detail when the shortwave infrared band is sharpened [5].

The use of Level 1C imagery introduces additional sensitivity to atmospheric and illumination differences. Future monitoring should preferentially use Sentinel 2 Level 2A surface reflectance, apply explicit cloud and shadow masks, and evaluate adaptive or scene specific thresholds against manually interpreted samples. During cloudy wet season periods, Sentinel 1 radar can complement optical observations, although radar speckle, emergent vegetation, and wind roughening require separate treatment [10].

The JRC comparison provides only a spatial reasonableness check because its temporal coverage does not include the 2023 observations. A formal accuracy assessment should use contemporaneous high resolution imagery or field shoreline points and report confusion matrix measures such as overall accuracy, precision, recall, and intersection over union. The exact Sentinel product identifiers and acquisition dates should also be archived in the final data package to ensure full reproducibility.

D. Management Implications

The workflow is suitable for routine screening because it converts freely available imagery into maps and area statistics with limited manual intervention. A monthly or biweekly implementation could flag deviations from the expected seasonal envelope, identify shoreline sectors undergoing persistent exposure, and support targeted inspection of semi inundated land. For operational decisions, the remotely sensed area should be combined with reservoir stage, rainfall, inflow, release, and demand data rather than used independently.

A practical monitoring dashboard could include three alert indicators: the difference from the historical area expected for the month, the proportion of water loss concentrated in shallow tributary arms, and the seasonal recovery achieved by the end of the wet season. Such indicators would help distinguish normal drawdown from a failure to replenish and could support early planning for irrigation allocation, downstream salinity control, and dry season water supply.

V. Conclusion

This study demonstrates that Dau Tieng Reservoir experienced a significant reduction in surface water extent between 2023 and 2025, driven primarily by an incomplete replenishment during the wet season. Utilizing a 10 m resolution Sentinel-2 NDWI workflow, the analysis quantified a moderate dry season area decline of 3.57% (660.60 ha), contrasted by a more severe wet season contraction of 8.37% (1,761.39 ha). Most importantly, the seasonal wet-to-dry expansion amplitude narrowed by 42.91%, dropping from 2,565.09 ha to 1,464.30 ha. Spatial mapping revealed that while the deeper southern core near the dam remained stable, water losses were heavily concentrated along the shallow, low-gradient northwestern margins and tributary arms. This uneven spatial footprint highlights planimetric area as a highly sensitive early warning indicator for structural changes in reservoir geometry and peripheral habitat exposure.

The findings confirm that a standardized Sentinel-2 imagery workflow can serve as an efficient, rapid screening tool for operational hydrological monitoring. However, since surface area variations are multi-causal, planimetric data cannot independently substitute for storage volume or pinpoint specific climate drivers. To enhance management utility, future research must transition to Sentinel-2 Level-2A surface reflectance data, incorporate Sentinel-1 radar observations to mitigate wet-season cloud cover, and conduct formal accuracy assessments against contemporaneous field data. Ultimately, integrating this satellite-derived screening workflow with in-situ gauge records—such as daily rainfall, reservoir stage, and controlled releases—will provide water managers with a robust, predictive framework to mitigate downstream salinity risks and optimize irrigation allocation in the face of shifting seasonal recovery cycles.

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